INSTITUTION

OF

MECHANICAL ENGINEERS.

PROCEEDINGS.

1874.

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Birmingham and Midland Bank, Birmingham.

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William P. Marshall.

Assistant Secretary.—Alfred Bache,

Institution of Mechanical Engineers,

81 *Newhall Street, Birmingham.*

LIST OF MEMBERS,

WITH YEAR OF ELECTION.

1874.

MEMBERS.

1861. Abel, Charles Denton, 20 Southampton Buildings, London, W.C.
1874. Abernethy, James, 2 Delahay Street, Westminster, S.W.
1848. Adams, William Alexander, Walford Manor, near Shrewsbury.
1859. Adamson, Daniel, Engineering Works, Hyde Junction, near Manchester.
1871. Adamson, Joseph, West View, Flowery Field, Hyde, near Manchester.
1861. Addenbrooke, George, Messrs. Addenbrookes Smith and Pidcock, Rough Hay Furnaces, Darlaston, near Wednesbury; and Greenhill, Wombourne, near Wolverhampton.
1851. Addison, John, 6 Delahay Street, Westminster, S.W.
1858. Albaret, Auguste, Engine Works, Liancourt-Rantigny, Oise, France.
1870. Alexander, Alfred, Corinium Iron Works, Cirencester.
1847. Allan, Alexander, Kenilworth Villa, South Cliff, Scarborough.
1865. Allen, William Daniel, Bessemer Steel Works, Sheffield.
1870. Alley, John, Locomotive Superintendent, Moscow and Razan Railway, Moscow: (or care of Messrs. Carruthers and Alley, 88 Bath Street, Glasgow.)
1865. Alleyne, Sir John Gay Newton, Bart., Butterley Iron Works, Alfreton.
1872. Alliott, James Bingham, Messrs. Manlove Alliott and Co., Bloomsgrove Works, Ilkeston Road, Nottingham.
1871. Allport, Howard Aston, Bestwood Coal and Iron Co., 40 Elm Avenue, Nottingham.
1861. Amos, Charles Edwards, 5 Cedars Road, Clapham Common, London, S.W.
1867. Amos, James Chapman, West Barnet Lodge, Lyonsdown, Barnet.
1856. Anderson, John, LL.D., F.R.S.E., 22 Victoria Road, Old Charlton, London, S.E.
1856. Anderson, William, Messrs. Easton and Anderson, Erith Iron Works, Erith, London, S.E.

1862. Angus, Robert, Locomotive Superintendent, North Staffordshire Railway, Stoke-upon-Trent.
1858. Appleby, Charles Edward, Renishaw Colliery, near Chesterfield.
1867. Appleby, Charles James, Messrs. Appleby Brothers, Emerson Street, Southwark, London, S.E.
1873. Appleby, Henry, Locomotive Superintendent, Monmouthshire Railway, Newport, Monmouthshire.
1874. Aramburu y Silva, Fernando, Messrs. Aramburu and Sons, Cartridge Manufacturers, Calle de la Virgen de las Azucenas, Madrid.
1874. Archer, David, General Manager, Messrs. Brown Marshalls and Co., Britannia Railway Carriage and Wagon Works, Birmingham.
1859. Armitage, William James, Farnley Iron Works, Leeds.
1866. Armstrong, George, Great Western Railway, Locomotive Department, Stafford Road Works, Wolverhampton.
1863. Armstrong, John, Timber Works and Saw Mills, 17 North Bridge Street, Sunderland.
1857. Armstrong, Joseph, Locomotive Superintendent, Great Western Railway, Swindon.
1858. Armstrong, Sir William George, C.B., D.C.L., LL.D., F.R.S., Elswick, Newcastle-on-Tyne; and Cragside, Morpeth.
1870. Armstrong, William Irving, Timber Works and Saw Mills, 17 North Bridge Street, Sunderland.
1873. Arnold, David Nelson, Manager, Midland Wagon Works, Lander Street, Birmingham.
1857. Ashbury, James Lloyd, M.P., 66 Grosvenor Street, London, W.
1873. Ashbury, Thomas, Assistant Manager, Ashbury Railway Carriage and Iron Works, Openshaw, Manchester.
1870. Atkinson, Charles Fanshawe, Messrs. Marriott and Atkinson, Fitzalan Steel Works, Sheffield.
1869. Austin, William Lawson, Messrs. Austin and Dodson, Cambria Steel and File Works, Arundel Street, Sheffield.
1869. Aveling, Thomas, Messrs. Aveling and Porter, Rochester.
1874. Ayton, Frederick, Hexham.

1865. Bagshawe, John J., Thames Steel Works, Sheffield.
1865. Bailey, John, Messrs. Courtney Stephens and Bailey, Blackhall Place Iron Works, Dublin.
1860. Bailey, Samuel, Mining Engineer, The Pleck, near Walsall.
1872. Bailly, Philimond, 49 Rue du Pont Neuf, Brussels.
1866. Baines, William, London Works, Soho, near Birmingham.
1873. Baird, George, Messrs. Baird, Iron Works, St. Petersburg; and 5A Cork Street, Burlington Gardens, London, W.

1866. Baker, Samuel, Engine and Boiler Works, 22 Oil Street, Liverpool.
1870. Barber, Thomas, Jun., Mining Engineer, High Park Collieries, Eastwood, Nottinghamshire.
1870. Barclay, Arthur, care of Hugh Barclay, Westfield, Surbiton, Kingston-on-Thames.
1860. Barclay, John, Bowling Iron Works, near Bradford, Yorkshire.
1860. Barker, Paul, Old Park Iron Works, Wednesbury.
1866. Barnard, Clement, 4 Billiter Square, London, E.C.
1862. Barrow, Joseph, Barr Hill Mount, Pendleton, Manchester.
1867. Barrows, Thomas Welch, Messrs. Barrows and Stewart, Portable Engine Works, Banbury.
1871. Barry, John Wolfe, 23 Delahay Street, Westminster, S.W.
1862. Barton, Edward, Carnforth Hæmatite Iron Works, Carnforth.
1860. Batho, William Fothergill, 9 Victoria Chambers, Victoria Street, Westminster, S.W.
1872. Bayliss, Thomas Richard, Adderley Park Rolling Mills and Metal Works, Birmingham ; and Elm Tree Villa, Smallheath, Birmingham.
1865. Beardshaw, Charles C., Baltic Steel Works, Sheffield.
1869. Beattie, William George, Locomotive and Carriage Superintendent, London and South Western Railway, Nine Elms, London, S.W.
1859. Beck, Edward, Dallam Forge, Warrington ; and Palmyra Square, Warrington. (*Life Member.*)
1873. Beck, William Henry, 139 Cannon Street, London, E.C.
1865. Bell, Charles, Messrs. Palmer and Bell, Agricultural Engineers, Taganrog, South Russia.
1858. Bell, Isaac Lowthian, F.R.S., Clarence Felling and Wylam Iron Works, Newcastle-on-Tyne ; and The Hall, Washington, County Durham.
1857. Bellhouse, Edward Taylor, Eagle Foundry, Hunt Street, Oxford Street, Manchester.
1868. Belliss, George Edward, Steam Engine and Boiler Works, Ledsam Street, Birmingham.
1854. Bennett, Peter Duckworth, Spon Lane Iron Foundry, Westbromwich.
1872. Bennett, William, Jun., 38 Sir Thomas' Buildings, Liverpool.
1865. Benson, George Henry, Messrs. Freeman Benson and Co., 9 Rumford Street, Liverpool.
1873. Bentley, John Greenwood, Manager, Lancashire Steel Works, Gorton, near Manchester.
1861. Bessemer, Henry, 4 Queen Street Place, New Cannon Street, London, E.C. ; and Denmark Hill, London, S.E.
1866. Bevis, Restel Ratsey, Manor Hill, Birkenhead.
1874. Bewick, Thomas John, Mining Engineer, 4 Broad Sanctuary, Westminster Abbey, Westminster, S.W. ; and Haydon Bridge, near Carlisle.

1870. Bewlay, Hubert, Birmingham Heath Boiler Works, Spring Hill, Birmingham.

1847. Beyer, Charles F., Messrs. Beyer Peacock and Co., Gorton Foundry, Manchester.

1861. Binns, Charles, Mining Engineer, Clay Cross, near Chesterfield.

1866. Birkbeck, John Addison, 8 Acklam Terrace, Newport Road, Middlesbrough.

1847. Birley, Henry, Haigh Foundry, near Wigan.

1870. Blair, John, Chief Locomotive Superintendent, Danish Government Railways, Aarhuus, Denmark.

1862. Blake, Henry Wollaston, F.R.S., Messrs. James Watt and Co., 18 London Street, London, E.C.

1867. Bleckly, John James, Bewsey Iron Works, Warrington ; and Daresbury Lodge, near Warrington.

1869. Bloomer, Benjamin Giles, The Sycamores, Pelsall, Walsall.

1862. Blyth, Alfred, Steam Engine Works, Fore Street, Limehouse, London, E.

1863. Boeddinghaus, Julius, Messrs. Heinrich Boeddinghaus and Sons, Elberfeld, Prussia.

1872. Boistel, Georges, 11 Rue de Châteauduu, Paris.

1872. Bolton, Major Francis John, 4 Broad Sanctuary, Westminster Abbey, Westminster, S.W.

1869. Borrie, John, Zetland Buildings, Middlesbrough.

1862. Bouch, Thomas, 78 George Street, Edinburgh.

1858. Bouch, William, Shildon Engine Works, Darlington.

1870. Bower, Anthony, Messrs. Forrester and Co., Vauxhall Foundry, Vauxhall Road, Liverpool.

1858. Bower, John Wilkes, Lancashire and Yorkshire Railway, Engineer's Office, Manchester. (*Life Member.*)

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1873. Bradbury, Charles Jordan, Heaton Terrace, Bury Old Road, Cheetham Hill, Manchester.

1854. Bragge, William, Messrs. John Brown and Co., Atlas Steel and Iron Works, Sheffield ; and Shirle Hill, Sheffield.

1854. Bramwell, Frederick Joseph, F.R.S., 37 Great George Street, Westminster, S.W.

1868. Breeden, Joseph, 157 Cheapside, Birmingham.

1848. Broad, Robert, Horseley Iron Works, near Tipton.

1865. Brock, Walter, Messrs. Denny and Co., Engine Works, Dumbarton.

1852. Brogden, Henry, Sale, near Manchester. (*Life Member.*)

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1866. Brown, Andrew Betts, Messrs. Brown Brothers and Co., Rosebank Iron Works, Edinburgh.
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1863. Brown, Henry, Waterloo Chambers, Waterloo Street, Birmingham.
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1869. Browne, Benjamin Chapman, Messrs. Hawthorn and Co., Newcastle-on-Tyne.
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1874. Bruce, George Barclay, 2 Westminster Chambers, Victoria Street, Westminster, S.W.
1867. Bruce, William Duff, Vice-Chairman, Port Commission, Calcutta.
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1870. Brunlees, James, 5 Victoria Street, Westminster, S.W.
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1865. Bryant, Frederick William, Albert Bridge Works, 49 Cheyne Walk, Chelsea, London, S.W.
1866. Bryham, William, Rose Bridge and Douglas Bank Collieries, near Wigan.
1873. Buckley, Robert Burton, Assistant Engineer, Indian Public Works Department, Buxar, Bengal, India : (or care of H. Burton Buckley, 1 St. Mary's Terrace, Paddington, London, W.)
1874. Buddicom, William Barber, Penbedw Hall, Mold, Flintshire.
1872. Budenberg, Arnold, Messrs. Schaeffer and Budenberg, 23 Lower King Street, Manchester.
1872. Bullock, Thomas, Jun., Messrs. Thomas Bullock and Sons, Button Manufacturers, Cliveland Street Works, Birmingham.
1870. Burgh, Nicholas Proctor, 78 Waterloo Bridge Road, London, S.E.
1874. Burn, William Edward, Managing Engineer, Ouseburn Engine Works, Newcastle-on-Tyne.
1871. Burrows, James, Douglas Bank, Wigan.
1870. Bury, William, 5 New London Street, London, E.C.
1873. Bury, William Tarleton, Messrs. Bury and Co., Regent Steel Works, Sheffield.
1856. Butler, Ambrose Edmund, Kirkstall Forge, near Leeds.
1859. Butler, John, Stanningley Iron Works, near Leeds.
1859. Butler, John Octavius, Kirkstall Forge, near Leeds.
1873. Butterfill, Henry Holt, 13 Humber Dock Street, Hull.

1871. Cabry, Charles, District Resident Engineer, North Eastern Railway, York.
1857. Cabry, Joseph, Resident Engineer, Blyth and Tyne Railway, Newcastle-on-Tyne.
1847. Cammell, Charles, Cyclops Steel and Iron Works, Sheffield.
1864. Campbell, David, 105 Eglinton Street, Glasgow.
1864. Campbell, James, Staveley Coal and Iron Works, Staveley, near Chesterfield.
1869. Campbell, James, Hunslet Engine Works, Leeds.
1860. Carbutt, Edward Hamer, Messrs. Thwaites and Carbutt, Vulcan Iron Works, Thornton Road, Bradford, Yorkshire.
1869. Carpmael, Frederick, 31 Berners Street, Ipswich.
1866. Carpmael, William, 24 Southampton Buildings, London, W.C.
1872. Carr, Thomas, Richmond Road, Montpelier, Bristol.
1868. Carrington, Thomas, Jun., Mining Engineer, Kiveton Park Colliery, near Sheffield.
1864. Carrington, William Thomas, Engineer to the Municipality, Singapore.
1874. Carrington, William T. H., 21 Gresham Street, Old Jewry, London, E.C.
1858. Carson, James Irving, Locomotive Superintendent, West Hartlepool Harbour and Railway, Stockton-on-Tees.
1870. Carver, James, Messrs. Carver and Mosley, Lace-Bobbin and Carriage Works, Butcher Street, Nottingham.
1869. Caspersen, Hans William, Engineer, Danish Government Railway Service ; 164 Rye Hill, Newcastle-on-Tyne.
1869. Chadwick, John, Prince's Bridge Iron Works, Water Street, Salford, Manchester.
1871. Chamberlain, Walter, Moor Green Hall, Moseley, near Birmingham.
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1872. Chatwin, Thomas, Victoria Works, Berkley Street, Birmingham.
1867. Chatwood, Samuel, Lancashire Safe and Lock Works, Bolton.
1869. Checkley, Thomas, Mining Engineer, Lichfield Street, Walsall.
1873. Cheesman, William Talbot, Hartlepool Rope Works, Hartlepool.
1857. Chrimes, Richard, Messrs. Guest and Chrimes, Brass Works, Rotherham.
1869. Clapham, Robert Calvert, Earsdon, near Newcastle-on-Tyne.
1866. Claridge, Thomas, Messrs. Claridge North and Co., Phœnix Foundry, near Bilston.
1871. Clark, Christopher Fisher, Mining Engineer, Garswood Coal and Iron Co., Park Lane Collieries, Wigan ; and Cranbury Lodge, Park Lane, Wigan.
1859. Clark, George, Southwick Engine Works, near Sunderland.
1867. Clark, George, Jun., Southwick Engine Works, near Sunderland.
1862. Clark, James, Wellington Foundry, Leeds.

1867. Clark, William, 9 Victoria Chambers, Victoria Street, Westminster, S.W.
1869. Clark, William, Mining Engineer, Teversall Collieries, near Mansfield.
1865. Clarke, John, Messrs. Hudswell Clarke and Rogers, Railway Foundry, Jack Lane, Leeds.
1869. Clarke, William, Messrs. Clarke Watson and Gurney, Victoria Works, South Shore, Gateshead.
1859. Clay, William, Messrs. Clay Inman and Co., Birkenhead Forge, Beaufort Road, Birkenhead ; and D 7 Exchange Buildings, Liverpool.
1870. Clayton, Nathaniel, Messrs. Clayton and Shuttleworth, Stamp End Iron Works, Lincoln.
1871. Cleminson, James, 5 Westminster Chambers, Victoria Street, Westminster, S.W.
1873. Clench, Frederick, Messrs. Robey and Co., Perseverance Iron Works, Lincoln.
1869. Clerk, Francis North, Mitre Galvanising Works, Bilston Road, Wolverhampton.
1866. Cleworth, Charles, District Locomotive Superintendent, East Indian Railway, Assensole, India ; and Park View, Rusholme, Manchester.
1847. Clift, John Edward, Mayfield, Cheltenham.
1858. Cochrane, Charles, Woodside Iron Works, near Dudley; and The Grange, Stourbridge.
1860. Cochrane, Henry, Ormesby Iron Works, Middlesbrough.
1854. Cochrane, John, 51 Queen's Gate Gardens, London, S.W.
1869. Cochrane, Joseph Bramah, Woodside Iron Works, near Dudley.
1868. Cochrane, William, Mining Engineer, Elswick Colliery, Elswick, Newcastle-on-Tyne ; and Oakfield House, Coxlodge, Newcastle-on-Tyne.
1867. Cockey, Francis Christopher, Selwood Iron Works, Frome.
1864. Coddington, William, Ordnance Cotton Mill, Blackburn.
1847. Coke, Richard George, Mining Engineer, Tapton Grove, Chesterfield.
1867. Coke, William Langton, Engineering Staff, Cape Government Railways, Cape of Good Hope : (or care of William Sacheverell Coke, Brookhill Hall, near Alfreton.)
1874. Conyers, William, Engineer, Locomotive Superintendent, and General Manager, Otago Railways, Dunedin, Otago, New Zealand.
1874. Cooper, William, Messrs. Gilbert and Cooper, Engineers and Iron Shipbuilders, Neptune Iron Works, Hull.
1848. Corry, Edward, 8 New Broad Street, London, E.C.
1868. Coulson, William, Mining Engineer, Shamrock House, Durham.
1870. Cowen, George Roberts, Beck Foundry, Brook Street, Nottingham.
1847. Cowper, Edward Alfred, 6 Great George Street, Westminster, S.W.
1847. Crampton, Thomas Russell, 4 Victoria Street, Westminster, S.W.

1871. Craven, Joseph, Messrs. Smith Beacock and Tannett, Victoria Foundry, Leeds.
1866. Craven, William, Vauxhall Iron Works, Osborne Street, Manchester.
1873. Crippin, Edward Frederic, Mining Engineer, Brynn Hall Colliery, Ashton, near Wigan.
1865. Cross, James, Messrs. John Hutchinson and Co., Alkali Works, Widnes; and Ditton Lodge, Warrington.
1869. Crossley, Louis J., Dean Clough Carpet Mills, Halifax.
1871. Crossley, William, Furness Iron and Steel Works, Askam, near Dalton-in-Furness, Lancashire.
1863. Crow, George, Messrs. R. Stephenson and Co.'s Works, Newcastle-on-Tyne.
1874. Curry, William, Locomotive Superintendent, Dublin and Drogheda Railway, Dublin.

1864. Daglish, George Heaton, St. Helen's Foundry, St. Helen's.
1869. Daglish, John, Mining Engineer, Tynemouth, near North Shields.
1866. Daniel, Edward Freer, Messrs. Thornewill and Warham's Iron Works, Burton-on-Trent; and 75 Branstone Road, Burton-on-Trent.
1866. Daniel, William, Messrs. John Fowler and Co.'s Steam Plough and Locomotive Works, Leeds.
1872. Danson, Thomas James, 3 St. Nicholas Buildings, Newcastle-on-Tyne.
1865. Darby, Abraham, Treberfydd, Bwlch, Brecknockshire.
1864. Darby, Charles E., Brymbo Iron Works, near Wrexham.
1873. Davey, Henry, Messrs. Hathorn Davis Campbell and Davey, Sun Foundry, Dewsbury Road, Leeds.
1865. Davidson, James, Royal Arsenal, Laboratory Department, Woolwich, S.E.
1874. Davis, Alfred, Messrs. Hathorn Davis Campbell and Davey, Sun Foundry, Dewsbury Road, Leeds; and 4 Westminster Chambers, Victoria Street, Westminster, S.W.
1868. Davis, Henry Wheeler, 11 New Broad Street, London, E.C.
1873. Davis, John Henry, Messrs. Nasmyth Wilson and Co., Bridgewater Foundry, Patricroft, near Manchester.
1873. Davy, David, Messrs. Davy Brothers, Park Iron Works, Sheffield.
1874. Davy, Walter Scott, Messrs. Davy Brothers, Park Iron Works, Sheffield.
1874. Daw, Samuel, 5 Dock Chambers, Cardiff.
1849. Dawes, George, Milton and Elsecar Iron Works, near Barnsley.
1861. Dawson, Benjamin, Engineer, Haswell Colliery, Fence Houses.
1869. Day, St. John Vincent, 166 Buchanan Street, Glasgow.
1874. Deacon, George Frederick, Borough Engineer, Municipal Offices, Dale Street, Liverpool.
1874. Deakin, Thomas, Sandon Street Engine Works, Broughton Road, Salford, Manchester.

1868. Dean, William, Great Western Railway, Locomotive Department, Swindon.
1866. Death, Ephraim, Albert Works, Leicester.
1858. Dees, James, Floraville, Whitehaven.
1858. Dempsey, William, 26 Great George Street, Westminster, S.W.
1872. Denton, John Punshon, 32 Bath Street, Southport.
1868. Derham, John J., Brookside, near Blackburn.
1865. Dircks, Henry, 48 Charing Cross, London, S.W. (*Life Member.*)
1865. Dobson, Benjamin, Messrs. Dobson and Barlow, Kay Street Machine Works, Bolton.
1872. Dobson, Benjamin Alfred, Messrs. Dobson and Barlow, Kay Street Machine Works, Bolton.
1868. Dodman, Alfred, St. James's Iron Works, Lynn.
1873. Donkin, Bryan, Jun., Messrs. B. Donkin and Co., Blue Anchor Road, Bermondsey, London, S.E.
1865. Douglas, Charles P., Consett Iron Works, near Blackhill, County Durham.
1857. Dove, George, Messrs. Cowans Sheldon and Co., St. Nicholas Iron and Engine Works, Carlisle.
1873. Dove, George, Jun., Assistant Engineer, Redbourn Hill Iron and Coal Co.'s Works, Frodingham, near Brigg.
1866. Downey, Alfred C., Messrs. Downey and Co., Coatham Iron Works, Middlesbrough ; and Royal Exchange, Middlesbrough.
1874. Dredge, James, 37 Bedford Street, Strand, London, W.C.
1847. Dübs, Henry, Glasgow Locomotive Works, Glasgow.
1870. Dunlop, James Wilkie, 22 Leadenhall Street, London, E.C.
1857. Dunlop, John Macmillan, Holehird, Windermere.
1864. Dunn, Thomas Edward, Kurhurballee Collieries, Chord Line East Indian Railway, viâ Muddapur Junction, India ; and The Cottage, Rusper, near Horsham.
1860. Dyson, George, Saltburn-by-the-Sea.
1865. Dyson, Robert, 16 Church Yard, Rotherham.

1869. Earnshaw, William Lawrence, Superintending Marine Engineer, South Eastern Railway, Folkestone.
1859. Eassie, Peter Boyd, Messrs. William Eassie and Co., Railway Saw Mills, Gloucester ; and 2 Brunswick Villas, Gloucester.
1858. Easton, Edward, Messrs. Eastons and Anderson, Grove, Southwark Street, London, S.E. ; and 7 Delahay Street, Westminster, S.W.
1867. Easton, James, Mining Engineer, Nest House, Gateshead.
1856. Eastwood, James, Messrs. Eastwood Swingler and Co., Victoria and Railway Iron Works, Derby.

1868. Eddison, Robert William, Messrs. John Fowler and Co., Steam Plough and Locomotive Works, Leeds.
1871. Edwards, Edgar James, Butterley Iron Works, Alfreton.
1866. Elce, John, Phœnix Iron Works, Jersey Street, Manchester.
1859. Elliot, Sir George, Bart., M.P., Houghton-le-Spring, near Fence Houses.
1869. Elliott, Henry Worton, Metal Sheathing Works, 10 Coleshill Street, Birmingham.
1870. Elsdon, Robert, 76 Manor Road, Upper New Cross, London, S.E.
1869. Elwell, Alfred, Edge Tool Works, Wood Green, Wednesbury.
1860. Elwell, Thomas, Messrs. Varrall Elwell and Middleton, 1 Avenue Trudaine, Paris.
1857. Evans, John Campbell, 8 Great George Street, Westminster, S.W.
1864. Everitt, William Edward, Messrs. Allen Everitt and Sons, Kingston Metal Works, Adderley Street, Birmingham; and Finstal, Bromsgrove.
1865. Evers, Frank, Cradley Iron Works, near Stourbridge.
1869. Eyth, Max, Messrs. John Fowler and Co.'s Steam Plough and Locomotive Works, Leeds.

1869. Faija, Henry, 30 John Street, Bedford Row, London, W.C.
1868. Fairbairn, Sir Andrew, Wellington Foundry, Leeds; and Goldsborough Hall, Knaresborough.
1869. Fairless, John, Forth Banks Engine Works, Newcastle-on-Tyne.
1867. Fardon, Thomas, Linslade Iron Works, Leighton Buzzard.
1865. Faviell, Samuel Clough, Messrs. Taylor Brothers and Co.'s, Clarence Iron Works, Leeds.
1872. Fearn, John Wilmot, Mining Engineer, 31 Devonshire Street, Chesterfield; and Newbold Road, Chesterfield.
1870. Ferguson, Henry Tanner, District Locomotive Superintendent, Great Indian Peninsula Railway, Bombay, India.
1854. Fernie, John, Bonchurch, Ventnor, Isle of Wight.
1866. Fiddes, Walter, Engineer, Bristol United Gas Works, Bristol.
1872. Fidler, Edward, Platt Lane Colliery, Wigan.
1867. Field, Edward, Chandos Chambers, Buckingham Street, Adelphi, London, W.C.
1861. Field, Joshua, 110 Westminster Bridge Road, Lambeth, London, S.E.
1874. Fielding, John, Messrs. Fielding and Platt, Atlas Iron Works, Gloucester.
1865. Filliter, Edward, Resident Engineer, Leeds Water Works, 16 East Parade, Leeds.
1868. Firth, Arthur, Leeds Iron Works, Leeds.
1868. Firth, Samuel, 16 York Place, Leeds.
1874. Firth, William, Burley Wood, Leeds.

1871. Fisher, Benjamin Samuel, Locomotive Superintendent, Somerset and Dorset Railway, Highbridge, near Bridgwater.
1864. Fleet, Thomas, Messrs. Fleet and Newey, Crown Boiler Works, Westbromwich.
1847. Fletcher, Edward, Locomotive Superintendent, North Eastern Railway, Gateshead.
1858. Fletcher, Henry Allason, Messrs. Fletcher Jennings and Co., Lowca Engine Works, Whitehaven. (*Life Member.*)
1872. Fletcher, Herbert, Ladyshore Colliery, Little Lever, Bolton; and The Hollins, Bolton.
1857. Fletcher, James, Messrs. W. Collier and Co., 2 Greengate, Salford, Manchester.
1866. Fletcher, James, Jun., Messrs. W. Collier and Co., 2 Greengate, Salford, Manchester.
1867. Fletcher, Lavington Evans, Chief Engineer, Association for the Prevention of Steam Boiler Explosions, 41 Corporation Street, Manchester.
1872. Flower, James J. A., Messrs. James Flower and Sons, Cape Town, Cape of Good Hope; and 9 America Square, Crutched Friars, London, E.C.
1859. Fogg, Robert, 11 Queen Anne's Gate, Westminster, S.W.
1861. Forster, Edward, Messrs. Chance Brothers and Co.'s Glass Works, Spon Lane, near Birmingham.
1869. Forster, George Baker, Backworth, Newcastle-on-Tyne.
1849. Forsyth, John C., North Staffordshire Railway, Stoke upon-Trent.
1861. Foster, Sampson Lloyd, Old Park Hall, Walsall.
1866. Fowler, George, Mining Engineer, Basford Hall, near Nottingham.
1847. Fowler, John, 2 Queen Square Place, Westminster, S.W.
1866. Fox, Charles Douglas, 5 Delahay Street, Westminster, S.W.
1859. Fraser, John, 18 York Place, Leeds.
1870. Freeman, George Frederick, 21 Cooper Street, Manchester.
1852. Froude, William, F.R.S., Chelston Cross, Torquay.
1866. Fry, Albert, Bristol Wagon Works, Temple Gate, Bristol.

1866. Galloway, Charles John, Messrs. W. and J. Galloway and Sons, Knott Mill Iron Works, Manchester.
1862. Galton, Capt. Douglas, C.B., R.E., F.R.S., Director of Works and Public Buildings, 12 Whitehall Place, London, S.W.; and 12 Chester Street, Grosvenor Place, London, S.W.
1870. Garstang, James H., General Manager, Signal Construction Works, Monmouth Street, Bridgwater.
1867. Gauntlett, William Henry, 9 Grange Road, Middlesbrough.
1871. Gibbins, Richard Cadbury, Berkley Street, Birmingham.

1870. Gibson, John, Engineer, Ryhope Colliery, near Sunderland.
1872. Gilbert, Ebenezer Edwin, Canada Engine Works, Montreal, Canada.
1856. Gilkes, Edgar, Messrs. Hopkins Gilkes and Co., Tees Engine Works, Middlesbrough.
1866. Gilroy, George, Engineer, Ince Hall Colliery, Wigan.
1874. Gjers, John, Messrs. Gjers Mills and Co., Ayresome Iron Works, Middlesbrough.
1862. Godfrey, Samuel, Messrs. Bolckow Vaughan and Co.'s Iron Works, Middlesbrough.
1867. Gooch, William Frederick, Vulcan Foundry, Warrington.
1869. Goodeve, Thomas Minchin, Goldsmith Buildings, Temple, London, E.C.
1865. Göransson, Göran Fredrick, Steel Works, Gefle and Hägbo, Sweden.
1871. Gowenlock, Alfred Hargreaves, care of Messrs. Jessop and Co., Railway Contractors, 93 Clive Street, Calcutta.
1869. Grainger, James Nixon, Public Works Department, Chepank, Madras: (or care of G. N. Henton, Newport, Isle of Wight.)
1865. Gray, John McFarlane, Board of Trade Steam Ship Surveyor, St. Katharine Dock House, London, E.
1870. Gray, Matthew, 106 Cannon Street, London, E.C.; and Silvertown Telegraph Works, North Woolwich, E.
1870. Greaves, James Henry, Albert Buildings, Queen Victoria Street, London, E.C.
1861. Green, Edward, Jun., Messrs. E. Green and Son, Phœnix Works, Wakefield.
1871. Greener, John Henry, 84 Lombard Street, London, E.C.
1874. Greenwood, William Henry, Assistant Manager, Steel and Ordnance Department, Sir Joseph Whitworth and Co., Chorlton Street, Manchester.
1865. Greig, David, Messrs. John Fowler and Co., Steam Plough and Locomotive Works, Leeds.
1874. Grew, Nathaniel, 8 New Broad Street, London, E.C.
1866. Grice, Edwin James, Cwmbran Nut and Bolt Works, near Newport, Monmouthshire.
1860. Grice, Frederic Groom, Ansty's Lea, Torquay.
1868. Grierson, Henry Houldsworth, Messrs. Ormerod Grierson and Co., St. George's Iron Works, Hulme, Manchester.
1873. Griffiths, John Alfred, Messrs. Griffiths Brothers and Co., Toowoomba Foundry, Ruthven Street, Toowoomba, Queensland: (or care of Thomas Griffiths, Higher Crumpsall, Cheetham Hill, Manchester.)
1874. Griffiths, John R., Manager, Ebbw Vale Co.'s Iron Works, Pontypool.
1871. Grover, Captain George Edward, R.E., Royal Engineers' Staff College, Farnborough Station.

1870. Guilford, Francis Leaver, Messrs. Cowen and Co., Beck Foundry, Brook Street, Nottingham.
1866. Gurden, Charles Frederick, Superintendent Engineer, Brazil and River Plate Steam Boat Co., 43 Bedford Street North, Liverpool.
1870. Gwynne, James Eglinton Anderson, Essex Street Works, Strand, London, W.C. (*Life Member.*)
1870. Gwynne, John, Hammersmith Iron Works, Hammersmith, London, W.

1863. Hackney, William, Pencoed, near Bridgend, Glamorganshire.
1861. Haggie, Peter, Hemp and Wire Rope Works, Gateshead.
1863. Hall, Joseph, Graz Iron Works, Graz, Styria, Austria.
1874. Hall, Thomas Bernard, Patent Nut and Bolt Works, Smethwick, near Birmingham.
1871. Hall, William Silver, Abbey Works, Nuneaton.
1871. Halpin, Druitt, Victoria Graving Docks, London, E.
1870. Hamand, Arthur Samuel, Stephenson Chambers, New Street, Birmingham.
1860. Hamilton, Gilbert, Messrs. James Watt and Co., Soho Foundry, near Birmingham ; and Leicester House, Kenilworth Road, Leamington.
1870. Hannah, Joseph Edward, Consett Water Works, Waskerley, Darlington.
1870. Harding, George Edward, 52 Broadway, New York.
1874. Harding, William Bishop, Beverley Iron and Wagon Works, Beverley.
1869. Harfield, William Horatio, Mansion House Buildings, Queen Victoria Street, London, E.C.
1873. Harman, Harry Jones, Engineer, Duke of Sutherland's Colliery, Brora, Sutherland.
1859. Harman, Henry William, Adelphi Hotel, John Street, Adelphi, London, W.C.
1873. Harris, Richard Henry, Malvern Link, Worcestershire.
1856. Harrison, George, Canada Works, Birkenhead.
1871. Harrison, Joseph Edward, Messrs. Cochrane and Co.'s, Woodside Iron Works, near Dudley.
1858. Harrison, Thomas Elliot, 1 Westminster Chambers, Victoria Street, Westminster, S.W.
1865. Harrison, William Arthur, Messrs. Allen Harrison and Co., Cambridge Street Works, Manchester.
1874. Hart, James, Messrs. David Hart and Co., North London Iron Works, Wenlock Road, City Road, London, N.
1872. Hartnell, Wilson, Rodborough, Stroud, Gloucestershire.
1871. Hartness, John, Lloyds' Inspector, Wear Chain and Anchor Testing Works, Sunderland.
1872. Hassall, Henry Thomas, Messrs. Hassall and Singleton, Phœnix Foundry, Freeman Street, Birmingham.

1858. Haswell, John A., North Eastern Railway, Locomotive Department, Gateshead.
1857. Haughton, S. Wilfred, Greenbank, Carlow, Ireland. (*Life Member.*)
1873. Hawkins, Charles W., Locomotive Superintendent, Great Indian Peninsula Railway, Byculla, Bombay.
1861. Hawkins, William Bailey, 2 Suffolk Lane, Cannon Street, London, E.C.
1870. Hawksley, Charles, 30 Great George Street, Westminster, S.W.
1856. Hawksley, Thomas, 30 Great George Street, Westminster, S.W.
1873. Hay, James A. C., Superintendent of Machinery to the War Department, Royal Arsenal, Woolwich, S.E.
1862. Haynes, Thomas John, Calpe Foundry and Forge, North Front, Gibraltar.
1869. Head, Jeremiah, Messrs. Fox Head and Co., Newport Rolling Mills, Middlesbrough.
1860. Head, John, Messrs. Ransomes Sims and Head, Orwell Works, Ipswich.
1873. Headly, Lawrance, Manager, Eagle Foundry, Mill Road, Cambridge.
1857. Healey, Edward Charles, 163 Strand, London, W.C.
1872. Heap, William, Bank Chambers, Cook Street, Liverpool.
1864. Heathfield, Richard, Lion Galvanising Works, Wiggin Street, Icknield Port Road, Birmingham.
1869. Henderson, David Marr, Engineer-in-Chief, Imperial Maritime Customs Service of China, Shanghai, China.
1865. Hetherington, John Muir, Vulcan Works, Pollard Street, Manchester.
1866. Hetherington, Thomas Ridley, Vulcan Works, Pollard Street, Manchester.
1864. Hetherington, William Isaac, 118 Cannon Street, London, E.C.
1865. Hewett, Edward Edwards, High Court, High Street, Sheffield.
1872. Hewlett, Alfred, Wigan Coal and Iron Works, Kirkless Hall, Wigan.
1872. Hewlett, William Henry, Wigan Coal and Iron Works, Kirkless Hall, Wigan.
1871. Hick, John, M.P., Mylton Hall, Whalley, near Blackburn.
1866. Hickman, George Haden, Groveland Iron Works, Dudley Port, Tipton.
1864. Hide, Thomas C., Messrs. Hide and Thompson, 4 Cullum Street, Fenchurch Street, London, E.C.
1870. Higson, John, Mining Engineer, St. George's Chambers, Albert Square, Manchester.
1873. Hildebrandt, John Albert Reinhold, Bow Chambers, 55 Cross Street, Manchester.
1871. Hill, Alfred C., Royal Exchange, Middlesbrough; and Newcomen Street, Coatham, Redcar.
1867. Hill, Henry Walker, 51 Hampden Street, Nottingham.
1873. Hilton, Franklin, Superintending Engineer, West Cumberland Iron and Steel Works, Workington.
1869. Hind, Henry, Central Engineering Tool Works, Queen's Road, Nottingham.

1874. Hird, Holmes, Engineer, Messrs. Bass and Co.'s Brewery, Burton-on-Trent.

1870. Hodges, Petronius, Yorkshire Steel and Iron Works, Penistone, near Sheffield.

1858. Hodgson, Robert, North Eastern Railway, Newcastle-on-Tyne.

1852. Holcroft, James, Norton, near Stourbridge.

1866. Holcroft, Thomas, Bilston Foundry, Bilston.

1871. Holiday, Joseph, Union Foundry, Cutler Heights, near Bradford, Yorkshire.

1865. Holliday, John, Meyrick House, Hill Top, Westbromwich.

1863. Holt, Francis, Midland Railway, Locomotive Department, Derby.

1873. Holt, Henry Percy, Royal Insurance Buildings, Leeds.

1867. Holt, William Lyster, 7 Great Winchester Street Buildings, London, E.C.

1867. Homer, Charles James, Mining Engineer, Chatterley Iron Works, Tunstall, near Stoke-upon-Trent.

1848. Homersham, Samuel Collett, 19 Buckingham Street, Adelphi, London, W.C.

1860. Hopkins, James Innes, 3 Southwell Gardens, Gloucester Road, South Kensington, London, S.W.

1866. Hopkins, John Satchell, Tinplate Works, Granville Street, Birmingham.

1856. Hopkinson, John, Messrs. Wren and Hopkinson, London Road Iron Works, Manchester.

1874. Hopkinson, John, Jun., D.Sc., Manager, Lighthouse and Optical Department, Messrs. Chance Brothers and Co.'s Glass Works, Spon Lane, near Birmingham.

1867. Hopper, William, Machine Works, Moscow : (or care of Thomas Hopper, 5 South Frederick Street, Edinburgh.)

1873. Horsley, Charles, 22 Wharf Road, City Road, London, N.

1868. Horsley, Thomas, Kirkby Old Hall, Pinxton, Alfreton.

1858. Horsley, William, Jun., Whitehill Point Iron Works, Percy Main, near Newcastle-on-Tyne.

1868. Horton, Enoch, Alma Works, Darlaston, near Wednesbury.

1871. Horton, George, Messrs. Horton and Son, Steam Boiler Works, 63 Park Street, Southwark, London, S.E.

1867. Horton, Thomas Ellwood, Lilleshall Iron Works, Oakengates, near Wellington, Shropshire.

1873. Hoskin, Richard, 2 Alliance Chambers, George Street, Sheffield.

1873. Hosking, John, Gateshead Iron Works, Gateshead.

1866. Houghton, John Campbell Arthur, Messrs. Cochrane and Co.'s, Woodside Iron Works, near Dudley.

1864. Howard, Eliot, Messrs. Hayward Tyler and Co., 84 Upper Whitecross Street, London, E.C.

1860. Howard, James, M.P., Messrs. J. and F. Howard, Britannia Iron Works, Bedford.
1867. Howard, Robert Luke, Messrs. Hayward Tyler and Co., 84 Upper Whitecross Street, London, E.C.
1860. Howe, William, Clay Cross Coal and Iron Works, near Chesterfield.
1861. Howell, Joseph Bennett, Brook Steel Works, Brookhill, Sheffield.
1867. Hughes, George Douglas, Queen's Foundry, London Road, Nottingham.
1873. Hughes, Henry, Falcon Iron Works, Loughborough.
1871. Hughes, Joseph, Parton Hæmatite Iron Works, near Whitehaven.
1864. Hulse, William Wilson, Whalley Chambers, 88 King Street, Manchester.
1866. Humphrys, Robert Harry, Deptford Pier, London, S.E.
1870. Hunstone, William Henry, Springfield Iron Works, Salford, Manchester.
1859. Hunt, James P., Corngreaves Iron Works, near Birmingham.
1856. Hunt, Thomas, 38 Nottingham Street, Sheffield.
1874. Hunt, William, Jun., Messrs. William Hunt and Sons, Alkali Works, Lea Brook, Wednesbury; and Aire and Calder Chemical Works, Castleford, near Normanton.
1872. Hunter, John Law, Borough Engineer, Wigan.
1864. Hutchinson, Edward, Messrs. Pease Hutchinson and Co., Skerne Iron Works, Darlington.
1865. Hyde, Lt.-Colonel Henry, R.E., Master of the Mint, Calcutta: (or care of Rev. H. M. C. Hyde, 184 The Grove, Camberwell, London, S.E.) (*Life Member.*)

1867. Inglis, William, Messrs. Hick Hargreaves and Co.'s, Soho Iron Works, Bolton.
1872. Inman, Charles Arthur, Messrs. Clay Inman and Co., Birkenhead Forge, Beaufort Road, Birkenhead.
1866. Ireland, William, care of Jonathan Ireland, Edward Street, Broughton Lane, Manchester.

1872. Jack, Alexander, Messrs. James Jack, Rollo, and Co., Victoria Engine Works, Boundary Street West, Vauxhall Road, Liverpool.
1870. Jackson, John P., Mining Engineer, Clay Cross Coal and Iron Works, near Chesterfield.
1859. Jackson, Matthew Murray, Engineer-in-Chief, Imperial Danube Steam Navigation Works, Pesth, Austria.
1847. Jackson, Peter Rothwell, Salford Rolling Mills, Manchester.
1860. Jackson, Samuel, Messrs. Charles Cammell and Co., Cyclops Steel and Iron Works, Sheffield.
1873. Jackson, Samuel, Assistant Locomotive Superintendent, Great Indian Peninsula Railway, Bombay: (or care of W. Albert Jackson, 1 Mulberry Street, Sheffield.)

1872. Jackson, William Francis, Hallside Steel Works, Newton, near Glasgow.
1873. Jacob, Edward Westley, Windsor Iron Works, Garston, near Liverpool.
1866. Jaeger, Herrmann Frederic, Messrs. Beyer Peacock and Co.'s Works, Gorton Foundry, Manchester.
1858. Jaffrey, George William, 40 St. Enoch Square, Glasgow; and The Firs, Partick Hill, Glasgow.
1856. James, Jabez, 40 Prince's Street, Commercial Road, Lambeth, London, S.E.
1870. Jamieson, John Lennox Kincaid, Messrs. John Elder and Co., Engineers and Shipbuilders, 12 Centre Street, Glasgow; and Govan, Glasgow.
1861. Jeffcock, Thomas William, Mining Engineer, 18 Bank Street, Sheffield.
1863. Jeffreys, Edward A., Low Moor Iron Works, near Bradford, Yorkshire.
1861. Jessop, Thomas, Messrs. William Jessop and Sons, Park and Brightside Steel Works, Sheffield.
1854. Jobson, John, Derwent Foundry, Derby.
1863. Johnson, Bryan, Hydraulic Engineering Works, Chester.
1861. Johnson, Samuel Waite, Locomotive Superintendent, Midland Railway, Derby.
1872. Joicey, Jacob Gowland, Messrs. J. and G. Joicey and Co., Forth Banks West Factory, Newcastle-on-Tyne.
1872. Jones, Charles, Messrs. John Jones and Sons, Marine Engine Works, William Street, Liverpool.
1871. Jones, Charles Henry, Assistant Locomotive Superintendent, Midland Railway, Derby.
1873. Jones, Edward, National Arms and Ammunition Works, Belmont Row, Birmingham.
1873. Jones, Edward Trygarn, Consulting Engineer to the Commercial Steam Ship Co., 32 Great St. Helen's, London, E.C.
1867. Jones, George Edward, Stockton Forge Co.'s Works, Stockton-on-Tees.
1857. Jones, Hodgson, 104 Maida Vale, London, W.
1869. Jones, John, Iron Trade Offices, Royal Exchange, Middlesborough.
1872. Jones, William Richard Sumption, Executive Engineer, Workshops Division, Lower Ganges Canal, Nurora, viâ Allgurh, India.

1857. Kay, James Clarkson, Phœnix Foundry, Bury, Lancashire.
1869. Keen, Arthur, Patent Nut and Bolt Works, Smethwick, near Birmingham.
1869. Keep, Alfred, Metal Sheathing Works, 10 Coleshill Street, Birmingham.
1867. Kellett, John, 27 King Street, Wigan.
1873. Kelson, Frederick Colthurst, Superintending Engineer, City of Cork Steam Packet Co., Cork.
1863. Kennan, James, Agricultural Implement Works, 19 Fishamble Street, Dublin.

1847. Kennedy, James, Cressington Park, Aigburth, Liverpool.
1863. Kennedy, John Pitt, Bombay Baroda and Central Indian Railway, 45 Finsbury Circus, London, E.C.; and 29 Lupus Street, St. George's Square, London, S.W.
1868. Kennedy, Thomas Stuart, Wellington Foundry, Leeds.
1866. Kershaw, John, 9 Great Queen Street, Westminster, S.W.
1872. King, William, Engineer, Liverpool United Gas Works, Duke Street, Liverpool.
1870. Kinsey, Henry, Postern Buildings, Swansea.
1872. Kirk, Alexander Carnegie, Messrs. John Elder and Co., Engineers and Shipbuilders, 12 Centre Street, Glasgow; and Govan, Glasgow.
1864. Kirtley, William, Locomotive Superintendent, London Chatham and Dover Railway, Longhedge Works, Wandsworth Road, London, S.W.
1859. Kitson, Frederick William, Monkbridge Iron Works, Leeds.
1848. Kitson, James, Airedale Foundry, Leeds.
1859. Kitson, James, Jun., Monkbridge Iron Works, Leeds.
1868. Kitson, John Hawthorn, Airedale Foundry, Leeds.
1874. Klein, Thorvald, Works Manager, Messrs. Brown Marshalls and Co., Britannia Railway Carriage and Wagon Works, Birmingham.

1872. Laird, Henry Hyndman, Messrs. Laird Brothers, Birkenhead Iron Works, Birkenhead.
1872. Laird, William, Messrs. Laird Brothers, Birkenhead Iron Works, Birkenhead.
1873. Lamb, William James, Newtown and Meadows Collieries, near Wigan.
1866. Lambert. William Blake, 6 Vanbrugh Park, Blackheath, London, S.E.
1863. Lancaster, John, Bilton Grange, Rugby.
1870. Lancaster, Joshua, Mostyn Coal and Iron Works, near Holywell.
1867. Lawrence, Henry, The Grange Iron Works, Durham.
1874. Laws, William George, Central Buildings, 18 Grainger Street West, Newcastle-on-Tyne.
1870. Layborn, Daniel, Messrs. Gladstone and Wyllie's Cotton Rice and Oil Factories, Rangoon, Burmah, India: (or care of Daniel Layborn, Sen., Beverley.)
1856. Laybourne, Richard, Rhymney Iron Works, Rhymney, Monmouthshire.
1860. Lea, Henry, 35 Paradise Street, Birmingham.
1865. Ledger, Joseph, Keswick.
1862. Lee, J. C. Frank, 22 Great George Street, Westminster, S.W.
1871. Lee, William, Messrs. Lee Clerk and Robinson, Gospel Oak Iron Works, Tipton.
1874. Lees, James, Long Island Iron Works, Carlisle.
1863. Lees, Samuel, Park Bridge Iron Works, Ashton-under-Lyne.

1863. Leigh, Evan, Town Hall Buildings, Manchester.
1866. Leigh, Joseph D., Ellesmere Foundry, Patricroft, near Manchester.
1870. Leonard, Edward James, East India Chambers, 23 Leadenhall Street, London, E.C.
1858. Leslie, Andrew, Iron Shipbuilding Yard, Hebburn Quay, Gateshead.
1872. Leslie, Bradford, 9 Victoria Chambers, Victoria Street, Westminster, S.W.
1872. Lewis, Richard Amelius, Messrs. John Spencer and Sons' Tyne Hæmatite Iron Works, Scotswood-on-Tyne.
1872. Lewis, Rowland Watkin, Britannia Boiler Tube Works, Ettingshall, Wolverhampton.
1860. Lewis, Thomas William, Bute Mineral Estate Office, Aberdare; and Mardy, Aberdare.
1856. Linn, Alexander Grainger, 9 Victoria Chambers, Victoria Street, Westminster, S.W.
1872. Linsley, Samuel W., Engineer, Whitburn Colliery, near Sunderland.
1866. Little, George, Messrs. Platt Brothers and Co.'s, Hartford Iron Works, Oldham.
1867. Livesey, James, 9 Victoria Chambers, Victoria Street, Westminster, S.W.
1873. Llewellyn, William Hely, Rhondda Engine Works, Pentre, Rhondda Valley, Pontypridd.
1867. Lloyd, Charles, Chatterley Iron Works, Tunstall, near Stoke-upon-Trent.
1863. Lloyd, Edward R., Albion Tube Works, Nile Street, Birmingham.
1871. Lloyd, Francis Henry, Old Park Iron Works, Wednesbury.
1854. Lloyd, George Braithwaite, Messrs. Lloyds, High Street, Birmingham. (*Life Member.*)
1862. Lloyd, John, Lilleshall Iron Works, Oakengates, near Wellington, Shropshire.
1847. Lloyd, Sampson, Old Park Iron Works, Wednesbury; and Areley House, near Bewdley.
1864. Lloyd, Sampson Zachary, Darlaston Steel and Iron Works, Wednesbury; and Areley Hall, Stourport.
1852. Lloyd, Samuel, The Farm, Sparkbrook, Birmingham.
1862. Lloyd, Wilson, Myvod House, Wood Green, Wednesbury.
1863. Loam, Matthew Hill, Engineer of the Gas and Water Works, Nottingham.
1869. Lockhart, Humphrey Campbell, Messrs. Pilkington Brothers' Plate Glass Works, St. Helen's.
1874. Logan, William, Mining Engineer, Langley Park Colliery, Durham.
1856. Longridge, Robert Bewick, Chief Engineer, Steam Boiler Insurance Company, 67 King Street, Manchester.
1865. Longridge, William Smith, Boyne Grove, Maidenhead.
1866. Lord, Edward, Canal Street Works, Todmorden.

1861. Low, George, St. Peter's Iron Works, Ipswich.
1873. Lowe, John Edgar, Engineer to Messrs. William Bird and Co., 2 Laurence Pountney Hill, London, E.C.
1873. Lucas, Arthur, 23 Delahay Street, Westminster, S.W.
1872. Lukin, Augustus Stephen, Newbold Road, Chesterfield.
1854. Lynde, James Gascoigne, Town Hall, Manchester.
1868. Lyndon, George Frederick, Minerva Works, Fazeley Street, Birmingham.
1872. Lyster, George Fosbery, Engineer-in-Chief, Mersey Dock Estate, Liverpool.

1864. Macfarlane, Walter, Saracen Foundry, Washington Street, Glasgow.
1864. Macnab, Archibald Francis, Japanese Government Service, Yokohama, Japan.
1865. MacNay, William, Shildon Engine Works, Darlington.
1865. Macnee, Daniel, Brinsworth Iron and Steel Works, Rotherham.
1873. Mair, John George, Manager, Messrs. Simpson and Co.'s Engine Works, Grosvenor Road, Pimlico, London, S.W.
1859. Manning, John, Messrs. Manning Wardle and Co., Boyne Engine Works, Hunslet, Leeds.
1862. Mansell, Richard Christopher, Carriage Superintendent, South Eastern Railway, Ashford.
1862. Mappin, Frederick Thorpe, Messrs. Thomas Turton and Sons, Sheaf Works, Sheffield.
1857. March, George, Messrs. Maclea and March, Union Foundry, Dewsbury Road, Leeds.
1856. Markham, Charles, Staveley Coal and Iron Works, Staveley, near Chesterfield.
1871. Marsh, Henry William, Winterbourne, near Bristol.
1865. Marshall, Francis Carr, Messrs. Hawthorn and Co., Newcastle-on-Tyne.
1862. Marshall, James, Lingdale Mines, Guisborough.
1871. Marshall, James, Messrs. Marshall Sons and Co., Britannia Iron Works, Gainsborough.
1859. Marshall, William Ebenezer, 1 Beech Grove Terrace, Leeds.
1847. Marshall, William Prime, 81 Newhall Street, Birmingham.
1859. Marten, Edward Bindon, Chief Engineer, Midland Steam Boiler Inspection and Assurance Company, 56 Hagley Street, Stourbridge.
1853. Marten, Henry John, Parkfield Iron Works, near Wolverhampton.
1867. Martin, William, 13 Avenue de la Reine Hortense, Paris.
1857. Martindale, Lt.-Colonel Ben Hay, C.B., R.E., General Manager, London and St. Katharine Docks, Dock House, 109 Leadenhall Street, London, E.C.
1854. Martineau, Francis Edgar, Globe Works, Cliveland Street, Birmingham.

1864. Martley, William, Locomotive Superintendent, London Chatham and Dover Railway, Longhedge Works, Wandsworth Road, London, S.W.
1867. Mather, William, Messrs. Mather and Platt, Salford Iron Works, Manchester.
1853. Maudslay, Henry, care of John Barnard, 8 Lancaster Place, Strand, London, W.C. (*Life Member.*)
1869. Maughan, Thomas, Engineer, Cramlington Colliery, Cramlington, Northumberland.
1873. Maw, William Henry, 37 Bedford Street, Strand, London, W.C.
1869. May, George, Mining Engineer, Harton Collieries, Tyne Docks, South Shields.
1861. May, Robert Charles, 6 Great George Street, Westminster, S.W.
1857. May, Walter, Messrs. May and Mountain, Suffolk Works, Berkley Street, Birmingham.
1865. Maylor, John, Churton Lodge, Churton, near Chester.
1859. Maylor, William, Messrs. Stanes Maylor and Co., Phœnix Coffee Works, Beypoor, Malabar Coast, India: (or care of Messrs. Stanes Watson and Co., 4 Cullum Street, Fenchurch Street, London, E.C.)
1874. McClean, Frank, 23 Great George Street, Westminster, S.W.
1872. McConnochie, John, Engineer to the Bute Harbour Trust, New Works, Bute Docks, Cardiff.
1865. McDonnell, Alexander, Locomotive Superintendent, Great Southern and Western Railway, Dublin.
1867. McEwen, James, Messrs. Firmstone and McEwen, Lays Iron Foundry, near Stourbridge.
1864. McEwen, Lawrence Thompson, Lombard House, George Yard, Lombard Street, London, E.C.
1868. McKay, Benjamin, Manager, Small Arms Factory, Small Heath, near Birmingham.
1872. McNeile, Alexander, Messrs. McNeile Brothers, Wheel and Axle Works, 26 John Street, Pentonville Road, London, N.
1863. Meek, Sturges, Resident Engineer, Lancashire and Yorkshire Railway, Manchester.
1858. Meik, Thomas, Messrs. Meik and Nisbet, 6 York Place, Edinburgh.
1857. Menelaus, William, Dowlais Iron Works, Dowlais.
1867. Merryweather, Richard M., Fire Engine Works, 63 Long Acre, London, W.C.
1862. Miers, Francis C., Messrs. Fry and Miers, 8 Great Winchester Street Buildings, London, E.C.; and Stoneleigh Lodge, Grove Road, Clapham Park, London, S.W.
1864. Miers, John William, 74 Addison Road, Kensington, London, W.
1874. Milburn, John, Hawkshead Foundry, Quay Side, Workington.
1862. Millward, John, Curzon Chambers, 27 Paradise Street, Birmingham.

1856. Mitchell, Charles, Iron Shipbuilding Yard, Low Walker, Newcastle-on-Tyne.
1870. Moberley, Charles Henry, Messrs. Eastons and Anderson's, Erith Iron Works, Erith, London, S.E.
1873. Möller, Peter T., Mining Engineer, Admiralty, St. Petersburg.
1872. Moon, Richard, Jun., Mersey Steel and Iron Works, Caryl Street, Liverpool.
1859. Moor, William, Engineer, Hetton Colliery, Hetton, near Fence Houses.
1864. Moore, Sampson, North Foundry, Cotton Street, Clarence Dock, Liverpool.
1872. Moorsom, Warren Maude, London and North Western Railway, Locomotive Department, Crewe.
1864. Morgan, Joshua Llewelyn, Llanelly Iron and Tinplate Works, near Abergavenny ; and Dan y Blorenge, near Abergavenny.
1867. Morgans, Thomas, Newarue, Lydney.
1874. Morris, Edmund Legh, Messrs. Woods Cocksedge and Co., Suffolk Iron Works, Stowmarket.
1868. Morris, William, Waldridge Colliery, Chester-le-Street.
1873. Morrison, Henry Martin, 15 Birch Lane, Longsight, Manchester.
1865. Morton, Robert, Alliance Chambers, Borough, London, S.E.
1865. Mosse, James Robert, Public Works Office, Colombo, Ceylon.
1858. Mountain, Charles George, Messrs. May and Mountain, Suffolk Works, Berkley Street, Birmingham.
1873. Muir, Alfred, Messrs. William Muir and Co., Britannia Works, Sherborne Street, Strangeways, Manchester.
1873. Muir, Edwin, Engineer, Rochdale Canal Navigation, Rochdale.
1863. Muir, William, 59 Shardeloes Road, New Cross, London, S.E.
1872. Mulliner, Charles, 29 Blackfriars, Manchester.
1865. Murdock, William Mallabey, Barrow Hæmatite Steel Works, Barrow-in-Furness.
1859. Murphy, James, Railway Works, Newport, Monmouthshire.
1858. Murray, Thomas H., Engine Works, Chester-le-Street.
1863. Musgrave, John, Jun., Globe Iron Works, Bolton.

1870. Napier, James Murdoch, Messrs. David Napier and Sons, Vine Street, York Road, Lambeth, London, S.E.
1848. Napier, John, Messrs. Robert Napier and Sons, Engineers and Shipbuilders, Lancefield House, Glasgow.
1856. Napier, Robert, West Shandon, Helensburgh. (*Life Member.*)
1861. Naylor, John William, Wellington Foundry, Leeds.
1858. Naylor, William, 57 Mildmay Park, Islington, London, N.
1863. Neilson, Walter Montgomerie, Hyde Park Locomotive Works, Glasgow.
1869. Nelson, James, King's House Engine Works and Foundry, Sunderland.
1860. Nettlefold, Joseph Henry, Screw Works, Broad Street, Birmingham.
1866. Newdigate, Albert Lewis, 2 The Pavement, Clapham Common, London, S.W. (*Life Member.*)

1862. Newton, William Edward, 66 Chancery Lane, London, W.C.
1866. Norfolk, Richard, Beverley Iron and Wagon Works, Beverley.
1850. Norris, Richard Stuart, Wilton Cottage, Kenyon, near Manchester.
1868. Norris, William Gregory, Coalbrookdale Iron Works, near Wellington, Shropshire.
1869. North, Frederic William, Mining Engineer, Rowley Hall Colliery, Rowley Regis, near Dudley.
1870. Nye, Henry, Messrs. Varrall Elwell and Middleton's Works, 1 Avenue Trudaine, Paris.

1868. O'Connor, Charles, Messrs. John Elder and Co.'s, Fairfield Engine Works, Govan, Glasgow.
1866. Oliver, William, Victoria and Broad Oaks Foundries, Chesterfield.
1867. Olrick, Lewis, 27 Leadenhall Street, London, E.C.
1864. Ommanney, Frederick Francis, New Bridge Foundry, Adelphi Street, Salford, Manchester.
1870. Osborn, Samuel, Clyde Steel and Iron Works, Sheffield.
1870. Osman, Joseph, Bey, Chief Engineer and Superintendent of Factories to the Khedive of Egypt, Boulac, Cairo ; and St. James's Hotel, 77 Piccadilly, London, W.
1867. Oughterson, George Blake, Messrs. Manlove Alliott and Co., 45 Rue d'Elbeuf, Rouen, France.
1847. Owen, William, Wheathill Foundry, Rotherham ; and Clifton House, Rotherham.

1868. Paget, Arthur, Machine Works, Loughborough.
1869. Palmer, Alfred Septimus, Mining Engineer, Quayside, Newcastle-on-Tyne.
1871. Parke, Frederick, Withnell Fire Clay Works and Cotton Mill, near Chorley.
1868. Parker, Henry, Locomotive Superintendent, Mexican Railway, Puebla, Mexico : (or care of Frederick Parker, 117 Unett Street, Birmingham.)
1872. Parker, Thomas, Carriage Superintendent, Manchester Sheffield and Lincolnshire Railway, Gorton, near Manchester.
1871. Parkes, Pershouse, Tipton Chain Works, Castle Street, Tipton.
1872. Paxman, James Noah, Messrs. Davey Paxman and Co., Standard Iron Works, Colchester.
1869. Peacock, Ralph, Messrs. Beyer Peacock and Co.'s Works, Gorton Foundry, Manchester.
1869. Peacock, Ralph, Aire and Calder Foundry, Goole.
1847. Peacock, Richard, Messrs. Beyer Peacock and Co., Gorton Foundry, Manchester.
1874. Peaker, George, Engineer to the Small Arms Ammunition Factory, Kirkee, India.

1873. Pearce, Richard, Deputy Carriage Superintendent, East Indian Railway, Howrah, Bengal, India.

1867. Pearce, Robert Webb, Carriage Superintendent, East Indian Railway, Howrah, Bengal, India.

1848. Pearson, John, 7 Old Hall Street, Liverpool.

1869. Pearson, William Hall, 50 Ann Street, Birmingham.

1866. Peel, George, Jun., Soho Iron Works, Pollard Street, Manchester.

1866. Peele, Arthur John, Oakley House, Bellevue, Shrewsbury.

1848. Penn, John, F.R.S., The Cedars, Lee, London, S.E. (*Life Member.*)

1873. Penn, John, Jun., Messrs. John Penn and Sons, Marine Engineers, Greenwich, S.E.

1873. Penn, William, Messrs. John Penn and Sons, Marine Engineers, Greenwich, S.E.

1874. Percy, Cornelius McLeod, Wigan Coal and Iron Co.'s Works, Kirkless Hall, Wigan.

1861. Perkins, Loftus, 6 Seaford Street, Regent Square, London, W.C.

1866. Perks, John Hartley, Shrubbery Iron Works, Wolverhampton; and Slade Hill, Wolverhampton.

1863. Perry, Thomas J., Highfields Engine Works, Bilston.

1865. Perry, William, Messrs. Samuel Perry and Sons, Wednesbury.

1869. Pickersgill, Thomas, Mining Engineer, Waterloo Main Colliery, Leeds.

1867. Pidgeon, Daniel, Messrs. Samuelson and Co., Britannia Iron Works, Banbury.

1871. Platt, James, Messrs. Fielding and Platt, Atlas Iron Works, Gloucester.

1867. Platt, Samuel Radcliffe, Messrs. Platt Brothers and Co., Hartford Iron Works, Oldham.

1870. Platt, William Wilkinson, Messrs. Mather and Platt, Salford Iron Works, Manchester; and Seymour Grove, Old Trafford, Manchester.

1869. Player, John, Clydach Foundry, near Swansea.

1866. Plum, Thomas Edward Day, Normanton Iron and Steel Works, Normanton.

1861. Plum, Thomas William, Old Park Iron Works, near Shiffnal.

1872. Pole, William, F.R.S., 31 Parliament Street, Westminster, S.W.

1860. Ponsonby, Edward Vincent, 1 Torquay Villa, Maindee, Newport, Monmouthshire.

1869. Potter, William Aubone, Mining Engineer, Cramlington House, Cramlington, Northumberland.

1864. Potts, Benjamin Langford Foster, 174 Camberwell Grove, London, S.E.

1851. Potts, John Thorpe, Messrs. Richmond and Potts, 119 South Fourth Street, Philadelphia, Pennsylvania, United States.

1870. Powell, Thomas, (Son), Messrs. Thomas and T. Powell, 23 Rue St. Julien, Rouen, France.

1874. Powell, Thomas, (Nephew), Messrs. Thomas and T. Powell, 23 Rue St. Julien, Rouen, France.
1867. Powell, William, Harbour Works, Douglas, Isle of Man.
1867. Pratchitt, John, Messrs. Pratchitt Brothers, Denton Iron Works, Carlisle.
1865. Pratchitt, William, Messrs. Pratchitt Brothers, Denton Iron Works, Carlisle.
1856. Preston, Francis, Turnbridge Forge, Huddersfield.
1866. Price, John, Chief Surveyor, Underwriters' Registry for Iron Vessels, 37 West Sunniside, Sunderland.
1874. Prosser, William Henry, Messrs. Harfield and Co.'s, Mansion House Buildings, Queen Victoria Street, London, E.C.
1866. Putnam, William, Darlington Forge, Darlington.

1873. Radcliffe, Arthur Henry Wright, 7 Union Street, Birmingham.
1870. Radcliffe, William, Messrs. Hampton Radcliffe and Co., Phœnix Bessemer Steel Works, The Ickles, near Sheffield.
1868. Rafarel, Frederic William, Cwmbran Nut and Bolt Works, near Newport, Monmouthshire.
1874. Rake, Herbert, Oxford Buildings, Swansea.
1864. Ramage, Robert, The Hollies, Sea Bank Road, North Egremont, near Birkenhead.
1847. Ramsbottom, John, Harewood Lodge, Mottram, near Manchester.
1866. Ramsden, Sir James, Abbot's Wood, Barrow-in-Furness.
1860. Ransome, Allen, Jun., 304 King's Road, Chelsea, London, S.W.
1869. Ransome, Robert Charles, Messrs. Ransomes Sims and Head, Orwell Works, Ipswich.
1862. Ransome, Robert James, Messrs. Ransomes and Rapier, Waterside Iron Works, Ipswich.
1873. Rapier, Richard Christopher, Messrs. Ransomes and Rapier, Waterside Iron Works, Ipswich ; and 5 Westminster Chambers, Victoria Street, Westminster, S.W.
1867. Ratcliff, Daniel Rowlinson, Messrs. Thomas Milner and Son, Phœnix Safe Works, Smithdown Lane, Edge Hill, Liverpool.
1867. Ratliffe, George, Mersey Steel and Iron Co.'s Works, Caryl Street, Liverpool.
1862. Ravenhill, John R., Glass House Fields, Ratcliff, London, E.
1872. Rawlins, John, Manager, Metropolitan Carriage and Wagon Co., Saltley Works, Birmingham.
1870. Reed, Edward James, C.B., M.P., 8 Victoria Chambers, Victoria Street, Westminster, S.W.
1859. Rennie, George Banks, Albion Iron Works, Holland Street, Blackfriars Road, London, S.E.; and 20 Lowndes Street, Lowndes Square, London, S.W.

1862. Reynolds, Edward, Messrs. Vickers Sons and Co., River Don Works, Sheffield.
1866. Richards, Edward Windsor, Ebbw Vale Iron Works, near Beaufort, Monmouthshire.
1856. Richards, Josiah, Pontypool Iron and Tinplate Works, Pontypool.
1863. Richardson, The Hon. Edward, Minister of Public Works, Christchurch, New Zealand.
1865. Richardson, John, Methley Park, near Leeds.
1873. Richardson, John, Engineer to Messrs. Robey and Co., Perseverance Iron Works, Lincoln.
1859. Richardson, William, Messrs. Platt Brothers and Co., Hartford Iron Works, Oldham.
1874. Riches, Tom Hurry, Locomotive Superintendent, Taff Vale Railway, Cardiff.
1873. Rickaby, Alfred Austin, Bloomfield Engine Works, Sunderland.
1874. Ricketts, Frederick Henry, Superintending Engineer to Messrs. Siemens Brothers, 12 Queen Anne's Gate, Westminster, S.W.
1863. Rigby, Samuel, Messrs. Armitage and Rigbys, Cock Hedge Mill, Warrington.
1871. Rigg, John, Deputy Locomotive Superintendent, London and North Western Railway, Crewe.
1874. Riley, James, Manager, Landore Siemens Steel Works, Landore, Swansea.
1873. Robertson, George, Messrs. Vickarys and Robertson, West of England Engineering Works, Exeter.
1848. Robertson, Henry, M.P., Great Western Railway, Shrewsbury.
1873. Robey, Robert, Jun., Trent Mining Co., Thrumpton, Keyworth, near Nottingham.
1874. Robinson, Henry, Messrs. Shelford and Robinson, 7 Westminster Chambers, Victoria Street, Westminster, S.W.
1859. Robinson, John, Messrs. Sharp Stewart and Co., Atlas Works, Manchester; and Westwood Hall, Leek, near Stoke-upon-Trent.
1865. Robinson, John, Messrs. Thomas Robinson and Son, Railway Works, Rochdale.
1866. Robson, Thomas, Mining Engineer, Lumley Colliery, Fence Houses.
1872. Rofe, Henry, Resident Engineer, Corporation Water Works, Rochdale.
1868. Rogers, William, Imperial Railway Department, Kobe, Japan.
1871. Rollo, David, Messrs. James Jack, Rollo, and Co., Victoria Engine Works, Boundary Street West, Vauxhall Road, Liverpool.
1853. Ronayne, Joseph P., Rinn Ronain, Queenstown, Ireland.
1867. Rose, Henry Fullwood, Albert Iron Works, Moxley, near Wednesbury.
1866. Rose, Thomas, Bradley Iron Works, near Bilston; and Merridale Grove, Wolverhampton.

1867. Rose, Thomas, Machine Works, 37 Victoria Street, Manchester.
1869. Rose, William Napoleon, Albert Iron Works, Moxley, near Wednesbury.
1874. Ross, John Alexander George, 1 St. Nicholas Buildings, Newcastle-on-Tyne.
1866. Rosthorn, Joseph De, Messrs. Rosthorn Brothers, Vienna.
1856. Rouse, Frederick, Great Northern Railway, Locomotive Department, Peterborough.
1857. Routledge, William, 4 Parsonage Buildings, Blackfriars, Manchester.
1860. Rumble, Thomas William, 15 St. Swithin's Lane, London, E.C. (*Life Member.*)
1867. Ruston, Joseph, Messrs. Ruston Proctor and Co., Sheaf Iron Works, Lincoln.
1866. Ryland, Frederick, Messrs. Kenrick's Works, Spon Lane, Westbromwich.

1866. Sacré, Alfred Louis, 26 Parliament Street, Westminster, S.W.
1859. Sacré, Charles, Locomotive Superintendent, Manchester Sheffield and Lincolnshire Railway, Gorton, near Manchester.
1868. Sacré, Edward Antoine, 26 Parliament Street, Westminster, S.W.
1864. Said, Colonel M., Pasha, Engineer, Turkish Service, Constantinople: (or care of J. C. Frank Lee, 22 Great George Street, Westminster, S.W.)
1872. Salmon, Frank Barton, Messrs. Clay Inman and Co., Birkenhead Forge, Beaufort Road, Birkenhead.
1859. Salt, George, Sir Titus Salt Bart., Sons and Co., Saltaire, near Bradford, Yorkshire.
1874. Sampson, James Lyons, Messrs. David Hart and Co., North London Iron Works, Wenlock Road, City Road, London, N.
1864. Samuda, Joseph D'Aguilar, M.P., Iron Ship Building Yard, Isle of Dogs, Poplar, London, E.
1848. Samuel, James, 5 Westminster Chambers, Victoria Street, Westminster, S.W.
1865. Samuelson, Bernhard, M.P., Britannia Iron Works, Banbury.
1871. Sanders, Richard David, Manager, Messrs. James Watt and Co., Soho Foundry, near Birmingham.
1861. Sanderson, George Grant, Redbourn Hill Iron and Coal Works, Frodingham, near Brigg.
1864. Sanderson, John, Weardale and Shildon District Water Works, Tunstall Reservoir, Wolsingham, near Darlington.
1874. Sauvée, Albert, 22 Parliament Street, Westminster, S.W.
1869. Scarlett, James, 14 St. Ann's Square, Manchester.
1866. Scholtze, Aleksander, Messrs. Scholtze Brothers, Engineers and Boiler Makers, Warsaw, Poland.
1868. Scott, George Lamb, Crown Iron Works, Heywood Street, Clowes Street, West Gorton, Manchester.

1861. Scott, Walter Henry, Locomotive and Carriage Superintendent, Mauritius Railways, Port Louis, Mauritius: (or care of James H. Murray, 14 Marquis Road, Finsbury Park, London, N.)

1868. Scriven, Charles, Messrs. Scriven and Holdsworth, Leeds Old Foundry, Marsh Lane, Leeds.

1864. Seddon, John, 98 Wallgate, Wigan.

1873. Seddon, John Frederick, Mining Engineer, Great Harwood Collieries, near Accrington.

1857. Selby, George Thomas, Smethwick Tube Works, Birmingham.

1867. Selby, Millin, Messrs. A. Karetnikoff and Son, Teakova Cotton Mill, near Ivanova, Vladimir, Russia: (or care of Atherton T. Selby, Atherton Old Hall, Leigh, near Manchester.)

1865. Sellers, William, Pennsylvania Avenue, Philadelphia, Pennsylvania, United States.

1872. Shanks, Arthur, Messrs. A. Burn and Co., Engineers and Contractors, 7 Hastings Street, Calcutta.

1863. Sharp, Henry, Bolton Iron and Steel Works, Bolton.

1867. Sharpe, Charles James, Stowe House, London Road, Twickenham.

1862. Sharpe, William John, 1 Victoria Street, Westminster, S.W.

1869. Sharrock, Samuel, Windsor Iron Works, Garston, near Liverpool.

1864. Shaw, Duncan, Mining Engineer, Cordoba, Spain.

1861. Shepherd, John, Union Foundry, Hunslet Road, Leeds.

1872. Shirley, Henry Lionel, Engineer, Constantinovskoi Railway, South Russia; and 9 Queen's Gate Terrace, London, S.W.

1872. Shoolbred, James Nelson, 3 York Buildings, Dale Street, Liverpool.

1859. Shuttleworth, Joseph, Messrs. Clayton and Shuttleworth, Stamp End Iron Works, Lincoln.

1851. Siemens, Charles William, D.C.L., F.R.S., 12 Queen Anne's Gate, Westminster, S.W.; and 3 Palace Houses, Kensington Gardens, Bayswater Road, London, W.

1871. Simon, Henry, 7 St. Peter's Square, Manchester.

1847. Sinclair, Robert, Goodrington House, Paignton, South Devon.

1857. Sinclair, Robert Cooper, Hartshill, near Atherstone.

1872. Slater, Alfred, Gloucester Wagon Works, Gloucester.

1859. Slater, Isaac, Gloucester Wagon Works, Gloucester.

1853. Slaughter, Edward, Clifton Park, Clifton, Bristol.

1866. Smethurst, Joseph, Guide Bridge Iron Works, Audenshaw, near Manchester.

1873. Smith, Charles, Manager, Messrs. Thomas Richardson and Sons, Hartlepool Iron Works, Hartlepool.

1866. Smith, Edward Fisher, The Priory Offices, Dudley.

1866. Smith, George Fereday, Grovehurst, Tunbridge Wells.

1860. Smith, Henry, Brierley Hill Iron Works, Brierley Hill.
1860. Smith, John, Brass Foundry, Traffic Street, Derby.
1857. Smith, Josiah Timmis, Ulverstone Hæmatite Iron Works, Barrow-in-Furness.
1859. Smith, Matthew, Caledonia Wire Mills, Halifax.
1857. Smith, William, 18 Salisbury Street, Strand, London, W.C.
1866. Smith, William, Messrs. A. and W. Smith and Co., Eglinton Engine Works, Glasgow.
1863. Smith, William Ford, Messrs. Smith and Coventry, Gresley Iron Works, Ordsal Lane, Salford, Manchester.
1871. Soames, Peter, 10 Southampton Street, Strand, London, W.C.
1859. Sokoloff, General Alexander, Engineer, Russian Imperial Service, Steam Marine Department, Cronstadt, Russia : (or care of Messrs. W. Collier and Co., 2 Greengate, Salford, Manchester.)
1858. Sörensen, Bergerius, Engineer-in-Chief, Royal Norwegian Navy Department, Horten Dockyard, Norway : (or care of Henry Tottie, 5 Great Winchester Street Buildings, London, E.C.)
1865. Sparrow, Arthur, Lane End Iron Works, Longton, near Stoke-upon-Trent.
1865. Sparrow, William Mander, Osier Bed Iron Works, Wolverhampton.
1866. Spencer, Eli, Messrs. Platt Brothers and Co., Hartford Iron Works, Oldham.
1867. Spencer, John W., Newburn Steel Works, Newcastle-on-Tyne.
1853. Spencer, Thomas, Black Ladies, Penkridge, near Stafford.
1854. Spencer, Thomas, Newburn Steel Works, Newcastle-on-Tyne.
1864. Spittle, Thomas, Cambrian Iron Foundry, Newport, Monmouthshire.
1862. Stableford, William, Railway Carriage Works, Oldbury, near Birmingham.
1869. Stabler, James, Messrs. Shand Mason and Co., Fire Engine Works, 75 Upper Ground Street, Blackfriars Road, London, S.E.
1874. Steel, Thomas Dyne, Bank Chambers, Newport, Monmouthshire.
1869. Stenson, Foster, Coalville, near Leicester.
1868. Stenson, William Towndrow, Whitwick Colliery, Coalville, near Leicester.
1866. Stephens, John Classon, Messrs. Ross Stephens and Walpole, North Wall Iron Works, Dublin.
1874. Stephens, Michael, Locomotive Superintendent, Cape Government Railways, Cape Town, Cape of Good Hope.
1868. Stephenson, George Robert, 24 Great George Street, Westminster, S W.
1866. Stevenson, John, Acklam Iron Works, Middlesbrough.
1859. Stewart, Charles P., Messrs. Sharp Stewart and Co., Atlas Works, Manchester ; and 92 Lancaster Gate, Hyde Park Gardens, London, W.
1851. Stewart, John, Blackwall Iron Works, Russell Street, Blackwall, London, E.

1867. Stirling, Patrick, Locomotive Superintendent, Great Northern Railway, Doncaster.
1864. Stokes, James Folliott, Rothney Cottage, Simla, India.
1873. Stonehouse, Marshall, Marine Surveyor to the Newcastle General Iron Steamship Insurance Association, Newcastle-on-Tyne.
1863. Storey, John Henry, Knott Mill Brass and Copper Works, Little Peter Street, Manchester.
1862. Strong, Joseph F., Rossetta Villa, Avenue Road, Southampton.
1865. Stroudley, William, Locomotive Superintendent, London Brighton and South Coast Railway, Brighton.
1873. Strype, William George, Manager, Custom-House Flour Mill, Store Street, Dublin; and 2 Sydenham Road, Dundrum, near Dublin.
1861. Sumner, William, 2 Brazenose Street, Manchester.
1870. Swann, James Vincent Russell, Commissioner of Deeds Office, Moscow, Russia.
1860. Swindell, James Evers, Parkhead Iron Works, Dudley; and Oldswinford, near Stourbridge.
1864. Swindell, James Swindell Evers, Summerhill, Kingswinford, near Dudley.
1872. Symington, William Weldon, Bowden Steam Mills, Market Harborough.

1861. Tangye, James, Messrs. Tangye Brothers, Cornwall Works, Soho, Birmingham; and Clement Street, Birmingham.
1859. Tannett, Thomas, Messrs. Smith Beacock and Tannett, Victoria Foundry, Leeds.
1873. Taylor, Charles Dyke, Mining Engineer, Devoran, Cornwall.
1861. Taylor, George, Messrs. Taylor Brothers and Co., Clarence Iron Works, Leeds.
1874. Taylor, Henry Enfield, Mining Engineer, 15 Newgate Street, Chester.
1858. Taylor, James, Britannia Engine Works, Cleveland Street, Birkenhead.
1862. Taylor, John, Mining Engineer, 6 Queen Street Place, Upper Thames Street, London, E.C.
1873. Taylor, John, Midland Foundry, Queen's Road, Nottingham.
1867. Taylor, Joseph, Derwent Foundry, 99 Constitution Hill, Birmingham.
1874. Taylor, Percyvale, Manager, Panther Lead Smelting Works, St. Philip's, Bristol.
1862. Taylor, Richard, Mining Engineer, 6 Queen Street Place, Upper Thames Street, London, E.C.
1872. Teague, William, Mining Engineer, Tincroft Mines, Redruth.
1864. Tennant, Charles, The Glen, Innerleithen, near Edinburgh. (*Life Member.*)
1867. Thomas, Joseph Lee, 16 Holland Road, Kensington, London, W.
1864. Thomas, Thomas, 34 West Bute Street, Cardiff; and Bronygarn Villa, Roath, Cardiff.

1874. Thomas, William Henry, 15 Parliament Street, Westminster, S.W.
1857. Thompson, Robert, Haigh Foundry, near Wigan.
1862. Thompson, William, Messrs. Thompson and Boyd, Spring Gardens Engine Works, Newcastle-on-Tyne.
1868. Thomson, John, Engine Works, 36 Finnieston Street, Glasgow.
1870. Thomson, William Sparks, 9 Victoria Chambers, Victoria Street, Westminster, S.W.
1868. Thornewill, Robert, Messrs. Thornewill and Warham, Burton Iron Works, Burton-on-Trent.
1861. Thwaites, Robinson, Messrs. Thwaites and Carbutt, Vulcan Iron Works, Thornton Road, Bradford, Yorkshire.
1862. Tolmé, Julian Horn, 1 Victoria Street, Westminster, S.W.
1873. Tomkins, Edward, Montpelier Place, Fairfield, Buxton.
1857. Tomlinson, Joseph, Jun., Resident Engineer and Locomotive Superintendent, Metropolitan Railway, Chapel Street Works, Edgware Road, London, N.W.
1867. Tonks, Edmund, Brass Works, Moseley Street, Birmingham.
1856. Tosh, George, North Lincolnshire Iron Works, Frodingham, near Brigg.
1860. Townsend, Thomas C., 16 Talbot Chambers, Shrewsbury.
1865. Trow, John James, Messrs. William Trow and Sons, Union Foundry, Wednesbury.
1873. Trow, Joseph, Messrs. William Trow and Sons, Union Foundry, Wednesbury; and Holyhead Road, Wednesbury.
1866. Turner, Frederick, Messrs. E. R. and F. Turner, St. Peter's Iron Works, Ipswich.
1872. Turton, Thomas, Liverpool Forge Company, Brunswick Dock, Liverpool.
1867. Tweddell, Ralph Hart, 14 Delahay Street, Westminster, S.W.
1874. Twibill, Joseph, Engineer and Ironfounder, Barrack Street, Tatton Street, Chester Road, Manchester.
1856. Tyler, Captain Henry Wheetley, R.E., Railway Department, Board of Trade, Whitehall, London, S.W.

1862. Upward, Alfred, 11 Great Queen Street, Westminster, S.W.
1872. Usher, Thomas, Messrs. Reay and Usher, South Hylton Iron Works, Sunderland.

1862. Vavasseur, Josiah, 28 Gravel Lane, Southwark, London, S.E.
1865. Vickers, Albert, Messrs. Vickers Sons and Co., River Don Works, Sheffield.
1861. Vickers, Thomas Edward, Messrs. Vickers Sons and Co., River Don Works, Sheffield.

1856. Waddington, John, 35 King William Street, London Bridge, London, E.C.
1865. Wainwright, William, West Central Wagon Works, Worcester.
1863. Wakefield, John, Locomotive Superintendent, Dublin Wicklow and Wexford Railway, Dublin.
1873. Waldenström, Eric Hugo, Manager, Broughton Copper Co.'s Works, Broughton Road, Manchester.
1872. Walker, Alexander, Locomotive Superintendent, Cambrian Railways, Oswestry.
1870. Walker, Alfred, Albion Iron Works, Aldwark, York.
1867. Walker, Benjamin, Messrs. Tannett Walker and Co., Goodman Street Works, Hunslet, Leeds.
1864. Walker, Bernard Peard, Eagle Foundry, Broad Street, Birmingham.
1867. Walker, Charles Clement, Midland Iron Works, Donnington, near Newport, Shropshire ; and Lilleshall Old Hall, near Newport, Shropshire.
1874. Walker, James, 2 Cookridge Street, Leeds.
1863. Walker, William Hugill, Messrs. Walker Eaton and Co., Wicker Iron Works, Sheffield.
1863. Wallace, William, Superintending Engineer, Montreal Ocean Steam Ship Works, Boundary Street North, Liverpool.
1865. Waller, George Arthur, Messrs. A. Guinness Son and Co., St. James' Gate Brewery, Dublin.
1868. Wallis, Herbert, Mechanical Superintendent, Grand Trunk Railway, Montreal, Canada.
1865. Walpole, Thomas, Messrs. Ross Stephens and Walpole, North Wall Iron Works, Dublin.
1864. Warden, Walter Evers, Phœnix Bolt and Nut Works, Handsworth, near Birmingham.
1856. Wardle, Charles Wetherell, Messrs. Manning Wardle and Co., Boyne Engine Works, Hunslet, Leeds.
1852. Warham, John R., Messrs. Thornewill and Warham, Burton Iron Works, Burton-on-Trent.
1874. Warner, Edward, Messrs. Woods Cocksedge and Co., Suffolk Iron Works, Stowmarket.
1874. Wass, John William, Messrs. Wright Wass and Co., 27 Quayside, Newcastle-on-Tyne.
1867. Watkin, William John Laverick, Mining Engineer, Pemberton Colliery, near Wigan.
1862. Watkins, Richard, Messrs. Jackson and Watkins, Canal Iron Works, Poplar, London, E.
1866. Watson, Robert, Engineer, Ferryhill Colliery, Ferryhill.
1862. Webb, Francis William, Locomotive Superintendent, London and North Western Railway, Crewe.

1872. Welch, Edward John Cowling, Fowellscombe, Ashford, near Staines.
1862. Wells, Charles, Moxley Iron and Steel Works, near Bilston.
1871. West, Henry Joseph, Messrs. Siebe West and Co., Mason Street, Westminster Bridge Road, Lambeth, London, S.E.
1874. West, Nicholas James, Messrs. Harvey and Co., Hayle Foundry, Hayle.
1862. Westmacott, Percy Graham Buchanan, Sir William G. Armstrong and Co., Elswick Engine Works, Newcastle-on-Tyne.
1867. Weston, Thomas Aldridge, 10 South Delaware Avenue, Philadelphia, Pennsylvania, United States: (or care of William T. Watts, 81 Parade, Birmingham.)
1874. Whalley, Arthur John, Prince's Street, Truro.
1867. Wheatley, Thomas, Locomotive Superintendent, North British Railway, Glasgow.
1856. Wheeldon, Frederick R., Highfields Engine Works, Bilston; and 16 Waterloo Road, Wolverhampton.
1872. Whieldon, William, Messrs. Whieldon and Cooke, Collinge Engineering Works, 190 Westminster Bridge Road, Lambeth, London, S.E.
1874. White, Henry Watkins, Superintending Engineer, H. M. Dockyard, Gibraltar.
1864. White, Isaias, Messrs. Portilla and White, Engineers and Iron Ship Builders, Seville, Spain: (or care of Isaac White, Pontardulais, Llanelly.)
1868. Whitehead, Peter Ormerod, Ilex Cotton Mill, Rawtenstall, near Manchester.
1859. Whitham, James, Perseverance Iron Works, Kirkstall Road, Leeds.
1873. Whitley, John Robinson, Railway Works, Hunslet Road, Leeds.
1863. Whitley, Joseph, New British Iron Works, Corngreaves, near Birmingham.
1865. Whitley, Joseph, Railway Works, Hunslet Road, Leeds.
1869. Whittem, Thomas Sibley, Wyken Colliery, Coventry.
1866. Whitwell, Thomas, Thornaby Iron Works, Stockton-on-Tees.
1847. Whitworth, Sir Joseph, Bart., D.C.L., LL.D., F.R.S., 44 Chorlton Street, Portland Street, Manchester; and The Firs, Fallowfield, Manchester.
1859. Wickham, Lamplugh Wickham, Low Moor Iron Works, near Bradford, Yorkshire.
1868. Wigram, Reginald, Messrs. John Fowler and Co.'s Steam Plough and Locomotive Works, Leeds.
1867. Wilkes, Gilbert, Bordesley Tube Mills, Liverpool Street, Birmingham.
1867. Wilkes, John, Bordesley Tube Mills, Liverpool Street, Birmingham.
1868. Wilkieson, Colonel Charles Vaughan, R.E., care of Messrs. Richardson and Co., 23 Cornhill, London, E.C.
1874. Williams, David, Manager, Pontypool Iron and Tinplate Works, Pontypool.
1865. Williams, Edward, Messrs. Bolckow Vaughan and Co.'s Iron Works, Middlesbrough.

1872. Williams, Sir Frederick Martin, Bart., M.P., Perran Foundry, Goonvrea, Perranarworthal, Cornwall.
1847. Williams, Richard, Patent Shaft Works, Wednesbury.
1859. Williams, Richard Price, 9 Great George Street, Westminster, S.W.
1869. Williams, Walter, Wednesbury Oak Iron Works, Tipton.
1873. Williams, William Lawrence, Manager, Messrs. Brown Brothers and Co., Rosebank Iron Works, Edinburgh.
1870. Willman, Charles, 1 Cleveland Terrace, Middlesbrough.
1856. Wilson, Edward, 9 Dean's Yard, Westminster, S.W.
1859. Wilson, George, Messrs. Charles Cammell and Co., Cyclops Steel and Iron Works, Sheffield.
1867. Wilson, Henry, Phœnix Brass Works, Stockton-on-Tees.
1865. Wilson, James Edwards, Brunswick House, Bromley, Kent.
1863. Wilson, John Charles, Avonside Engine Works, St. Philip's, Bristol.
1857. Wilson, Robert, Messrs. Nasmyth Wilson and Co., Bridgewater Foundry, Patricroft, near Manchester.
1872. Wilson, Stephen, Engineer, Wearmouth Colliery, Sunderland.
1873. Wilson, Thomas Sipling, Messrs. Wilson and Jessop, 71 Cornhill, London, E.C.
1865. Winby, Clifford Etches, Messrs. Winby Brothers, Atlas Iron Works, Cardiff.
1867. Winby, Frederick Charles, Manor House, Cardiff.
1862. Winby, William Edward, Rabone Bridge Iron Works, Smethwick, near Birmingham; and 77 Wellington Road, Edgbaston, Birmingham.
1872. Winn, Charles William, 30 Easy Row, Birmingham.
1872. Winstanley, Robert, Jun., Mining Engineer, Lancaster Avenue, Fennel Street, Manchester.
1859. Winter, Thomas Bradbury, 28 Moorgate Street, London, E.C.
1872. Wise, William Lloyd, Chandos Chambers, Buckingham Street, Adelphi, London, W.C.
1872. Withinshaw, John, Birmingham Engine Works, Wiggin Street, Icknield Port Road, Birmingham.
1871. Withy, Edward, Messrs. Withy and Co., Middleton Iron Shipbuilding Yard, Hartlepool.
1868. Wood, Lindsay, Mining Engineer, Southhill, near Chester-le-Street.
1873. Woodhead, John Proctor. Whalley Chambers, 88 King Street, Manchester.
1851. Woodhouse, John Thomas, Mining Engineer, Midland Road, Derby.
1858. Woods, Hamilton, Liver Foundry, Ordsal Lane, Salford, Manchester.
1874. Worsdell, Thomas William, London and North Western Railway, Locomotive Department, Crewe.
1860. Worthington, Samuel Barton, Resident Engineer, London and North Western Railway, Manchester.

1866. Wren, Henry, Messrs. Wren and Hopkinson, London Road Iron Works, Manchester.
1870. Wright, George Benjamin, Goscote Iron Works, near Walsall.
1867. Wright, John Roper, Hallside Steel Works, Newton, near Glasgow.
1867. Wright, John Turner, Universe Rope Works, Garrison Street, Birmingham.
1859. Wright, Joseph, Metropolitan Carriage and Wagon Company, Saltley Works, Birmingham.
1860. Wright, Joseph, Neptune Forge, Chain and Anchor Works, Tipton.
1863. Wright, Owen, Broadwell Forge, Oldbury, near Birmingham.
1863. Wright, Peter, Railway Wheel Vice and Anchor Works, Dudley.
1871. Wright, William, Lostwithiel.
1871. Wrightson, Thomas, Messrs. Head Wrightson and Co., Teesdale Iron Works, Stockton-on-Tees.
1865. Wyllie, Andrew, Messrs. Forrester and Co., Vauxhall Foundry, Vauxhall Road, Liverpool.

1873. Young, Charles Frederic Trelawny, 112 St. Donatt's Road, New Cross, London, S.E.
1874. Young, James, Managing Engineer, Lambton Colliery Works, Fence Houses.
1861. Yule, William, 102 New Canal, St. Petersburg.

HONORARY LIFE MEMBERS.

1865. Downing, Samuel, LL.D., Trinity College, Dublin; and 4 The Hill, Monkstown, near Dublin.
1847. Fairbairn, Sir William, Bart., LL.D., F.R.S., The Polygon, Ardwick, Manchester.
1867. Morin, General Arthur, Director, Conservatoire National des Arts et Métiers, Paris.
1867. Tresca, Henri, Engineer Sub-Director, Conservatoire National des Arts et Métiers, Paris.

ASSOCIATES.

1865. Barker, Frederick, Leeds Iron Works, Leeds.
1873. Barry, William Henry, 7 Birchin Lane, London, E.C.
1867. Blinkhorn, William, London and Manchester Plate Glass Works, Sutton, St. Helen's.
1866. Crossley, John, British Plate Glass Works, Ravenhead, near St. Helen's.
1867. Dewhurst, John Bonny, Bellevue Cotton Mills, Skipton.

1863. Forster, George Emmerson, Contractor's Office, Washington, County Durham.
1873. Freeman, William George, Messrs. John Freeman and Sons, Granite Works, Penryn, Cornwall.
1865. Gössell, Otto, 22 Moorgate Street, London, E.C.
1865. Hall, John, 56 King Street, Manchester.
1874. Hardcastle, Robert Anthony, Clarence Iron Works, Leeds.
1874. Hurman, James, Traffic Superintendent, Taff Vale Railway, Cardiff; and 22 Albert Terrace, Charles Street, Cardiff.
1858. Lawton, Benjamin C., Corbridge, Northumberland.
1859. Leather, John Towlerton, Leventhorpe Hall, near Leeds. (*Life Associate.*)
1865. Longsdon, Alfred, Crown Buildings, Queen Victoria Street, London, E.C.
1860. Manby, Cordy, Castle Street, Dudley.
1868. Matthews, Thomas Bright, Messrs. Turton Brothers and Matthews, Phœnix Steel Works, Sheffield.
1874. Paget, Berkeley, Low Moor Iron Office, 98 Cannon Street, London, E.C.
1865. Parry, David, Leeds Iron Works, Leeds.
1864. Parsons, Charles T., Ann Street, Birmingham.
1871. Patterson, John, Liverpool and Manchester District Bank, Spring Gardens, Manchester; and Craigdarragh, Belfast.
1874. Pepper, Joseph Ellershaw, Monkbridge Iron Works, Leeds.
1856. Pettifor, Joseph, Midland Railway, Derby.
1859. Sherriff, Alexander Clunes, M.P., Great Western Railway, Worcester; and 10 Dean's Yard, Westminster, S.W.
1864. Tennant, John, St. Rollox Chemical Works, Glasgow. (*Life Associate.*)
1864. Thornton, Falkland Samuel, Bradford Street, Birmingham.
1869. Varley, John, Farnley Iron Works, Leeds.
1865. Warden, Thomas, Lionel Street, Birmingham.
1858. Waterhouse, Thomas, Claremont Place, Sheffield. (*Life Associate.*)

GRADUATES.

1874. Allen, Frank, Messrs. Allen Alderson and Co., Gracechurch Street, Alexandria: (or care of Messrs. Stafford Allen and Sons, 7 Cowper Street, Finsbury, London, E.C.)
1872. Armstrong, Thomas, 37 Westmorland Terrace, Newcastle-on-Tyne.
1872. Bagshaw, Walter, Victoria Foundry, Batley.
1869. Bainbridge, Emerson, Nunnery Colliery Offices, New Haymarket, Sheffield.
1869. Blake, Frederick William, Birmingham Heath Boiler Works, Spring Hill, Birmingham.

1874. Browne, Tomyns Reginald, Locomotive Works, Midland Railway, Derby.
1866. Butler, Thomas Snowden, Kirkstall Forge, near Leeds.
1873. Collingham, Robert Moss, Green Lane Foundry, Hull.
1873. Dobson, Richard Joseph Caistor, Sugar Fabric Trankil, Pattie, Japara, Java: (or care of Richard Dobson, Dolforwyn Hall, Abermule, Montgomeryshire.)
1868. Dugard, William Henry, 77 Lower Loveday Street, Birmingham.
1873. Edmunds, John Sharp Wilbraham, Stephenson Metal Tube Works, Liverpool Street, Birmingham.
1869. Fenwick, Clennell, Victoria Docks Engine Works, Victoria Docks, London, E.
1867. Flavel, Sidney, Jun., Eagle Foundry, Leamington.
1850. Glydon, George, Spring Hill Tube and Metal Works, Eyre Street, Birmingham.
1874. Hedley, Henry, Locomotive Works, Midland Railway, Derby.
1874. Hedley, Thomas, Locomotive Works, Midland Railway, Derby.
1867. Holland, George, care of John Holland, Navigation Old Yard, Castle, Northwich.
1868. Mappin, Frank, Messrs. Thomas Turton and Sons' Sheaf Works, Sheffield.
1867. Mayhew, Horace, Mining Engineer, Hindley House, near Wigan.
1867. Mitchell, John, Swaithe Colliery, Barnsley.
1868. Moor, William, Jun., Lanelay Colliery, Llantrissant, Glamorganshire.
1872. Napier, Robert Twentyman, Messrs. Simpson and Co.'s Engine Works, Grosvenor Road, Pimlico, London, S.W.
1867. Pearson, John Edward, Golborne Park, near Newton-le-Willows, Lancashire.
1870. Pearson, Thomas Henry, Moss Side Iron Works, Ince, near Wigan.
1874. Raukeilor, William Collis, Wednesbury Oak Iron Works, Tipton.
1873. Ratcliff, John Francis, Phœnix Safe Works, Smithdown Lane, Edge Hill, Liverpool.
1873. Simpson, Alfred, Messrs. Fowler and McCollin's, Vulcan Iron Works, Scott Street, Hull.
1870. Smith, Michael Holroyd, Caledonia Wire Mills, Halifax.
1874. Stephenson, Joseph, Chatterley Iron Works, Tunstall, near Stoke-upon-Trent.
1874. Taylor, Arthur, 6 Queen Street Place, Upper Thames Street, London, E.C.
1871. Thurgood, Ernest Charles, Messrs. Greenwood and Batley's Works, Armley Road, Leeds.
1868. Wicksteed, Joseph Hartley, Well House Foundry, Meadow Road, Leeds.
1872. Wilson, Alfred, 9 St. John's Terrace, Middlesbrough.

Accumulator.

Fig. 1. *Sectional Plan.*

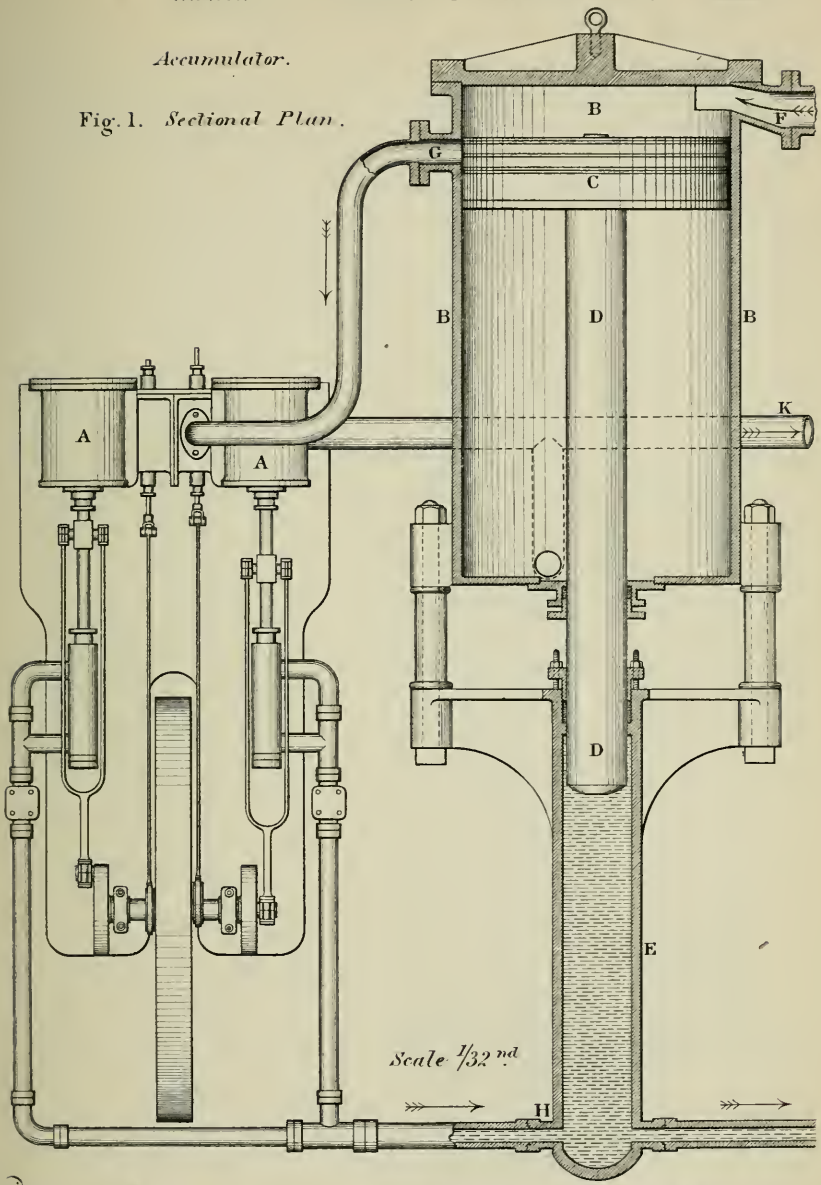
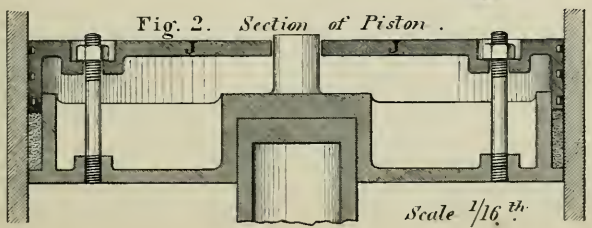


Fig. 2. *Section of Piston.*



(*Proceedings Inst. M.E. 1874.*)

Hydraulic Reversing Gear.

Fig. 3.

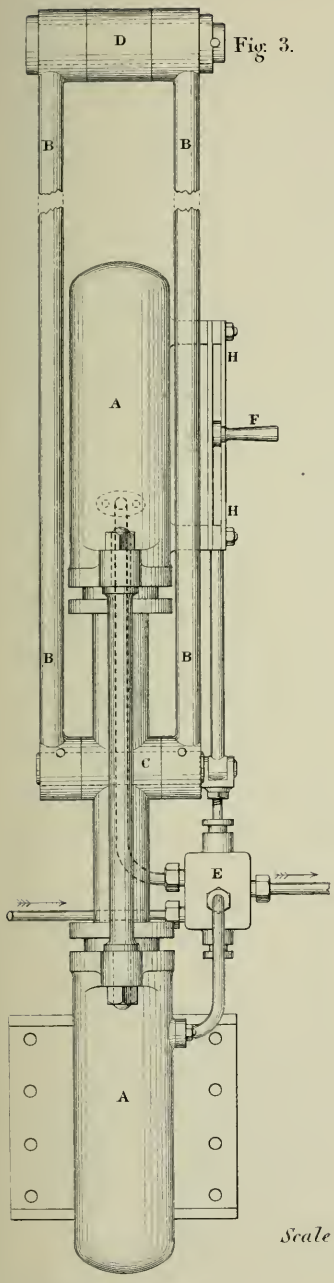
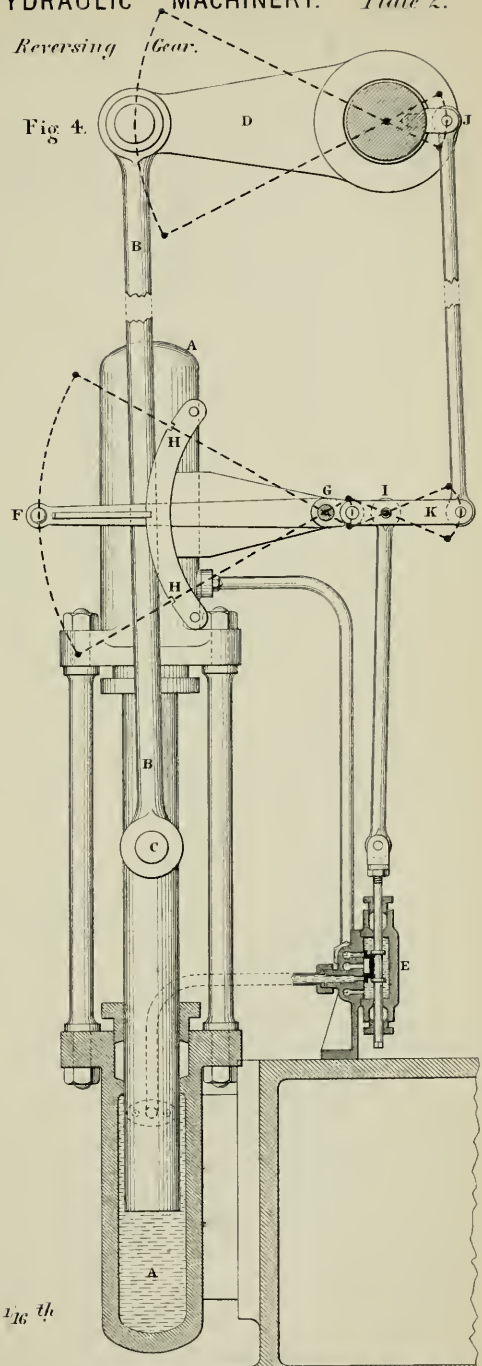


Fig. 4.



Scale $\frac{1}{16}$ *th*

(Proceedings Inst. M. E. 1874.)

Ins. 12 6 0 1 2 3 4 Feet.

Hydraulic Reversing Gear.

Diagrams showing changes of position.

Fig. 5.

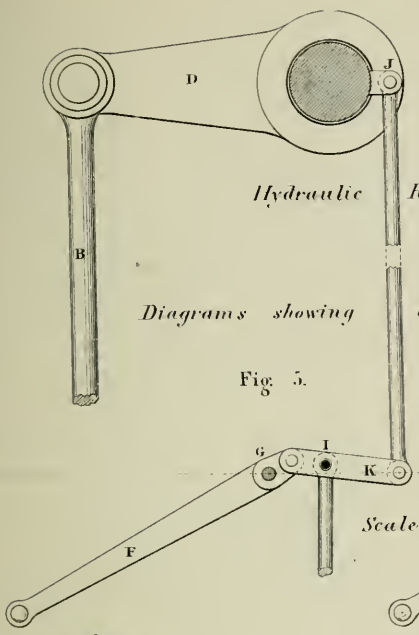
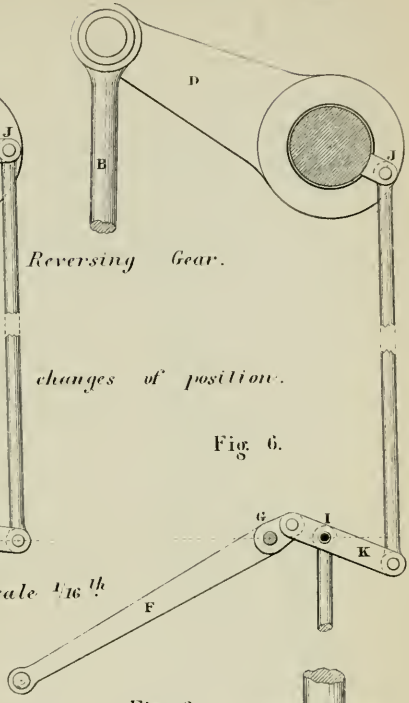


Fig. 6.



Scale 1/16 th

Fig. 7.
Sectional Plan.
Scale 1/16 th

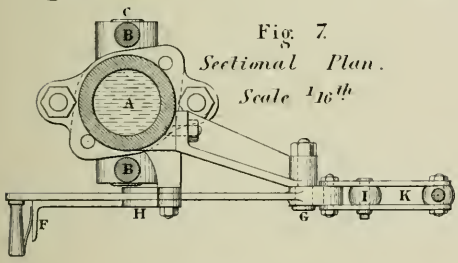


Fig. 8.
Slide Valve.
Vertical Section.
Scale 1/4 th

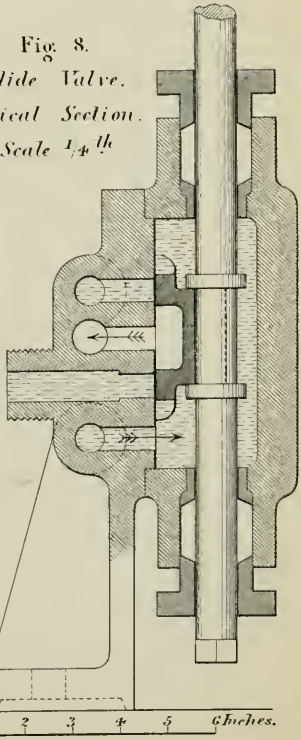
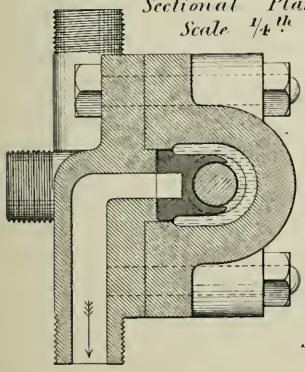
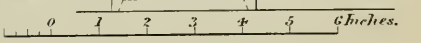


Fig. 9. *Slide Valve.*
Sectional Plan.
Scale 1/4 th



Scale 1/4 th



(Proceedings Inst. M. E. 1874.)

MARINE HYDRAULIC MACHINERY. *Plate 4.*

Steam Reversing Gear.

Fig. 10.

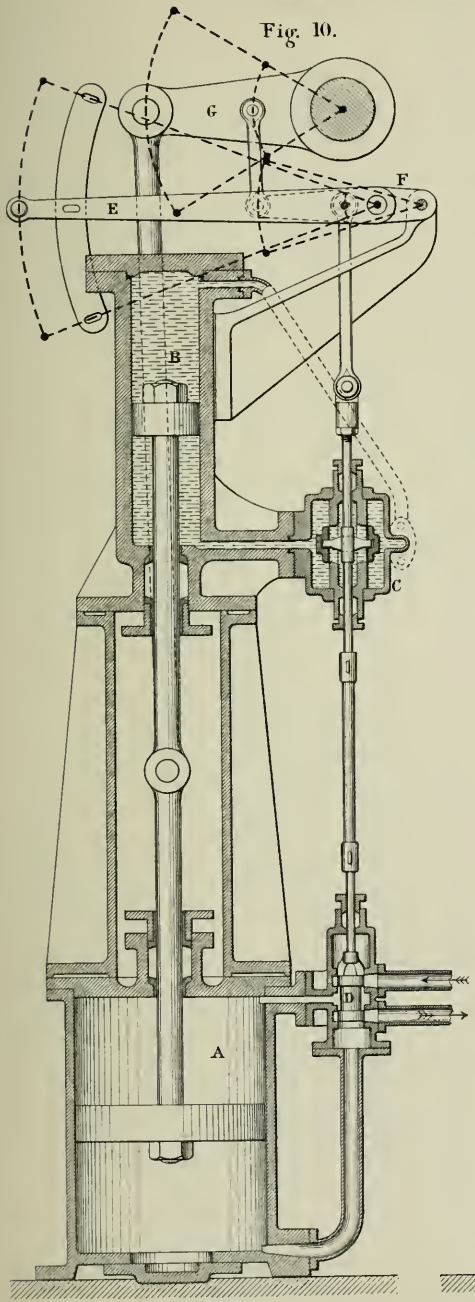
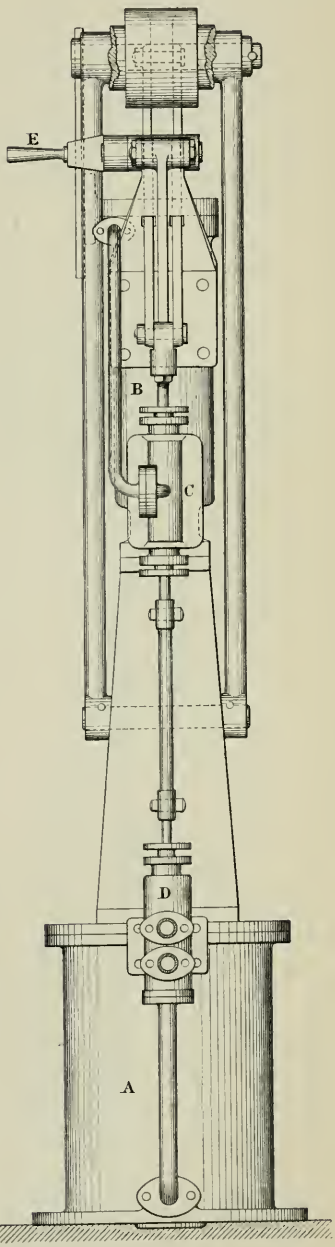


Fig. 11.



(Proceedings Inst. M. E. 1874.)

Scale 1/16 th

Ins. 12 6 0 1 2 3 4 Feet.

Steam Reversing Gear.

Diagrams showing changes of position.

Fig. 12.

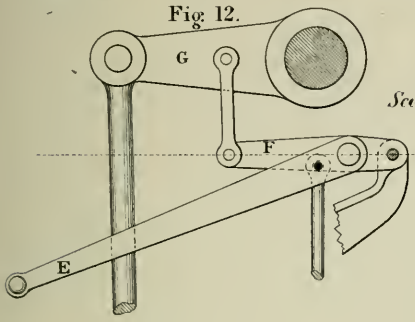
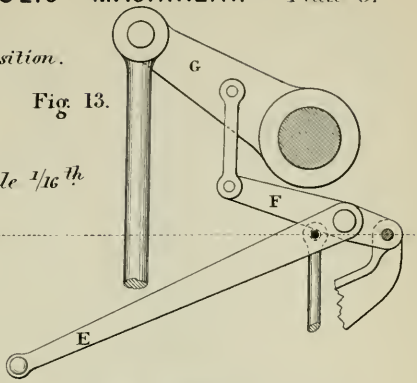


Fig. 13.



Scale 1/16 th

Fig. 14. *Sectional Plan.*

Scale 1/16 th

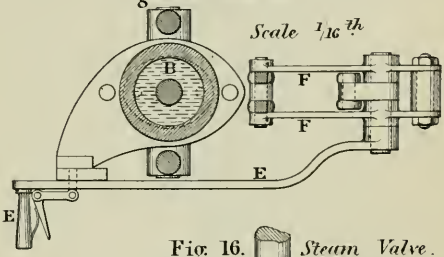


Fig. 15. *Water Valve.*

Scale 1/4 th

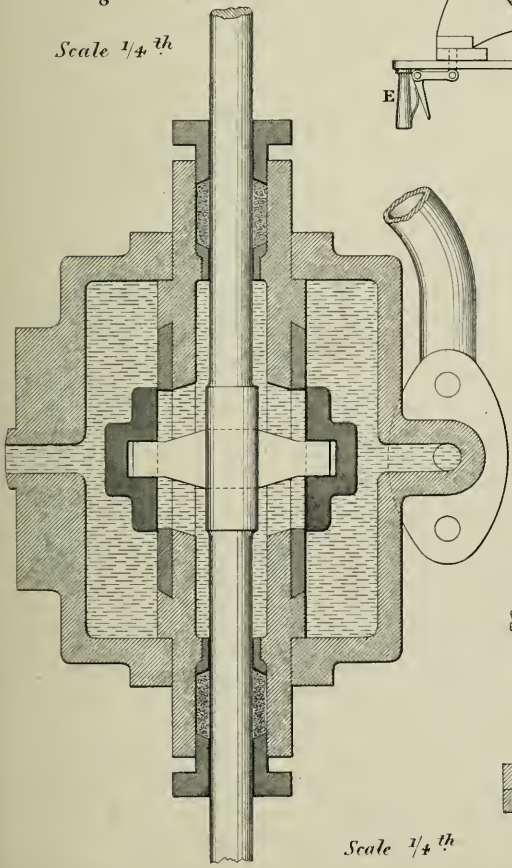
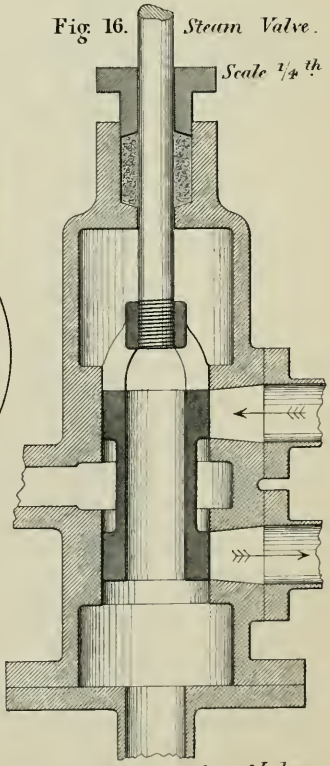


Fig. 16. *Steam Valve.*

Scale 1/4 th



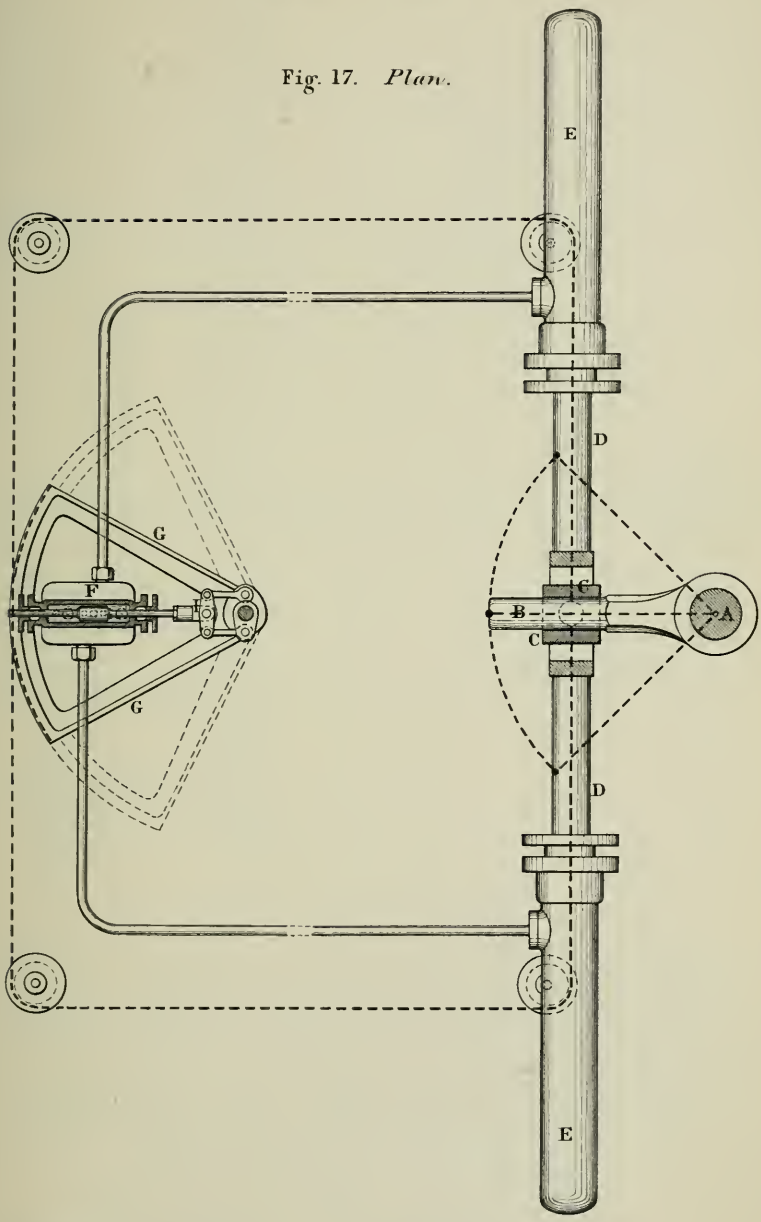
Scale 1/4 th

0 1 2 3 4 5 6 Inches.

(*Proceedings Inst. M.E. 1874.*)

Hydraulic Steering Gear.

Fig. 17. *Plan.*



(Proceedings Inst. M. E. 1874.)

Scale 1/20th.

Ins. 12 6 0 1 2 3 4 5 Feet.

Hydraulic Steering Gear.

Fig. 18.

Vertical Section.
Scale 1/20 th

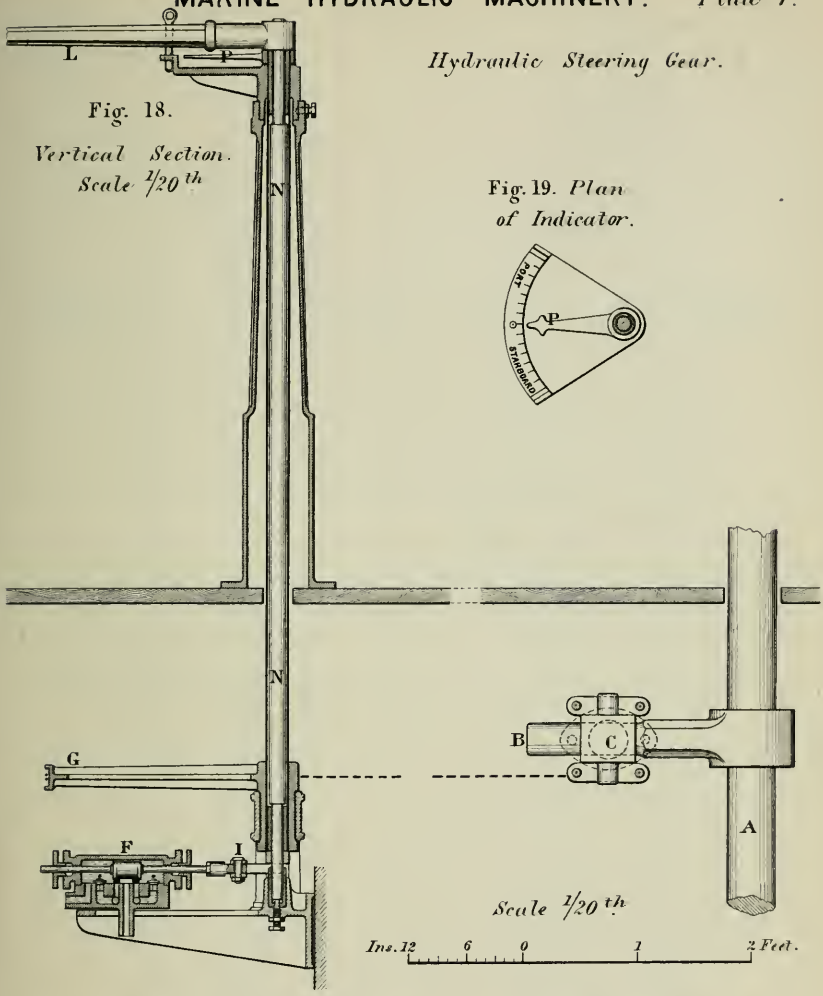
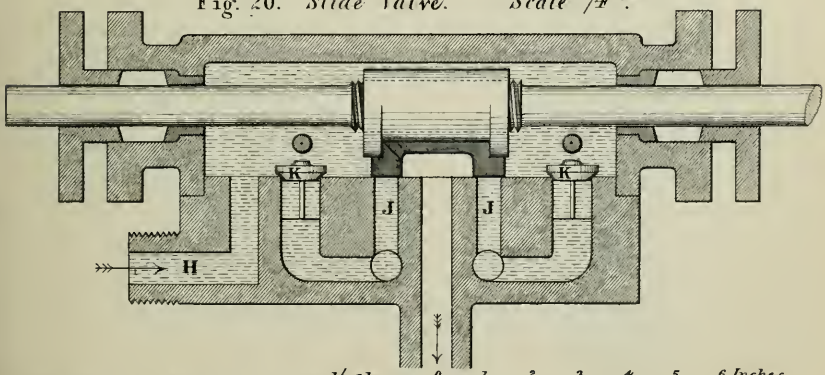


Fig. 19. *Plan of Indicator.*

Fig. 20. *Slide Valve.* *Scale 1/4 th*



(*Proceedings Inst. M.E. 1874.*) *Scale 1/4 th*

Hydraulic Hoist.

Fig: 21.

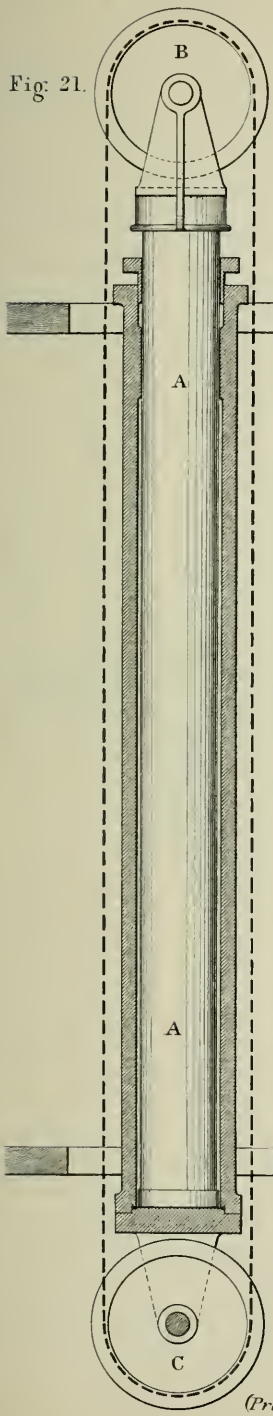
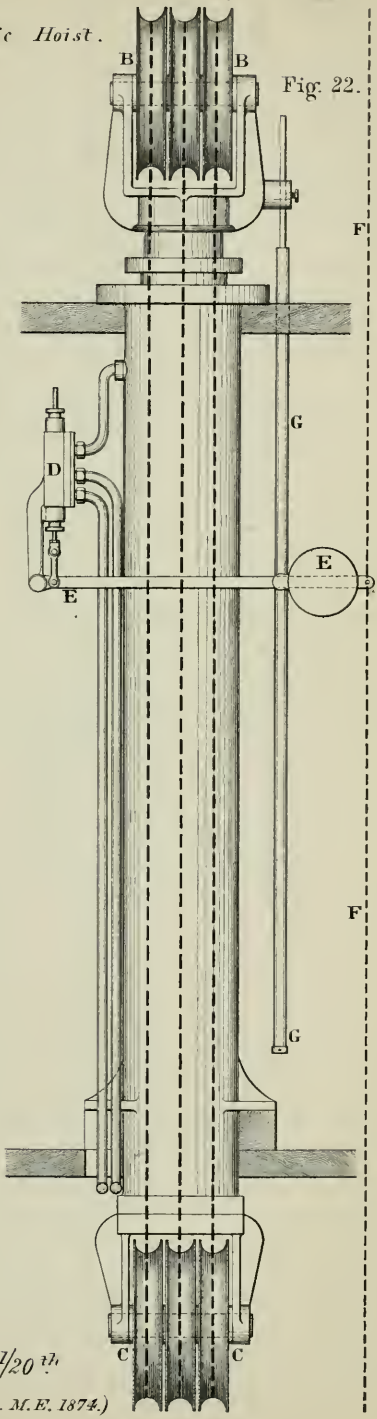


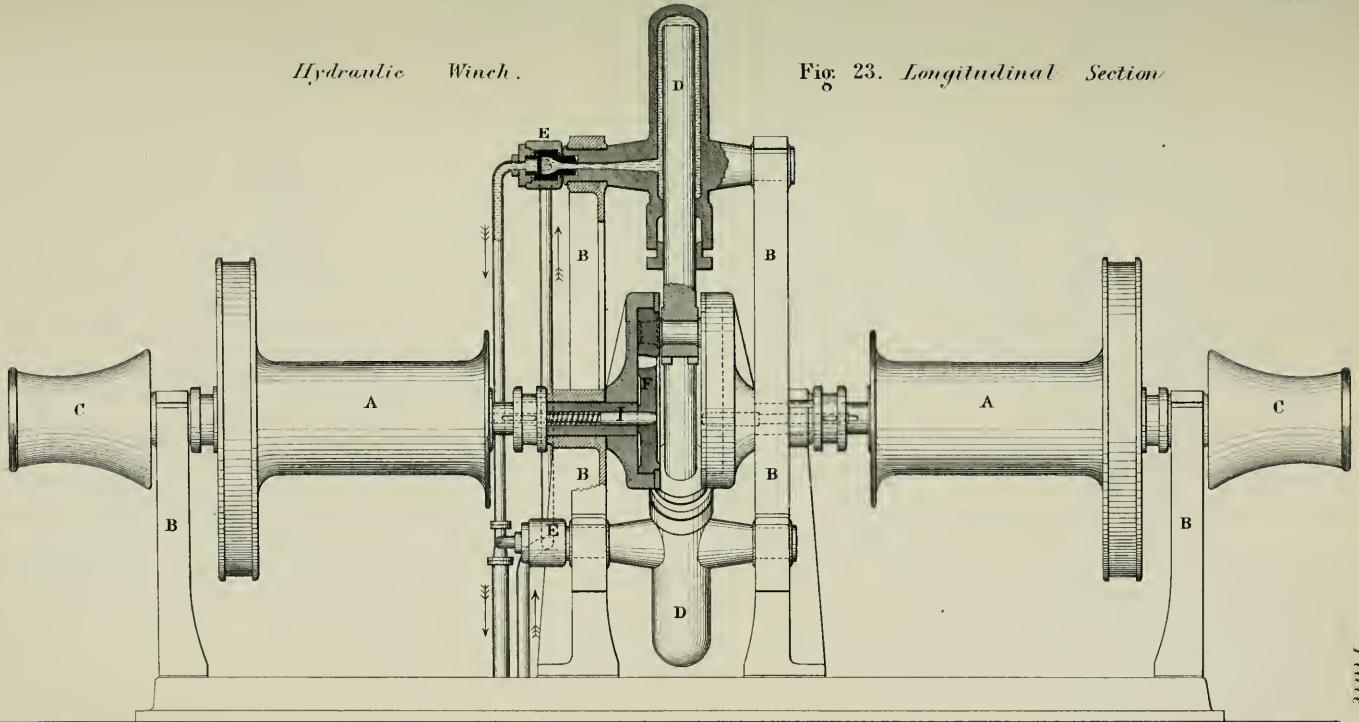
Fig: 22.



Scale 1/20 th.

(Proceedings Inst. M.E. 1874.)

Hydraulic Winch. Fig. 23. *Longitudinal Section.*



(Proceedings Inst. M.E. 1874.) Scale 1/20th. Ins. 12 6 0 1 2 3 4 5 Feet.

Plate 9.

MARINE HYDRAULIC MACHINERY.

Hydraulic Winch.

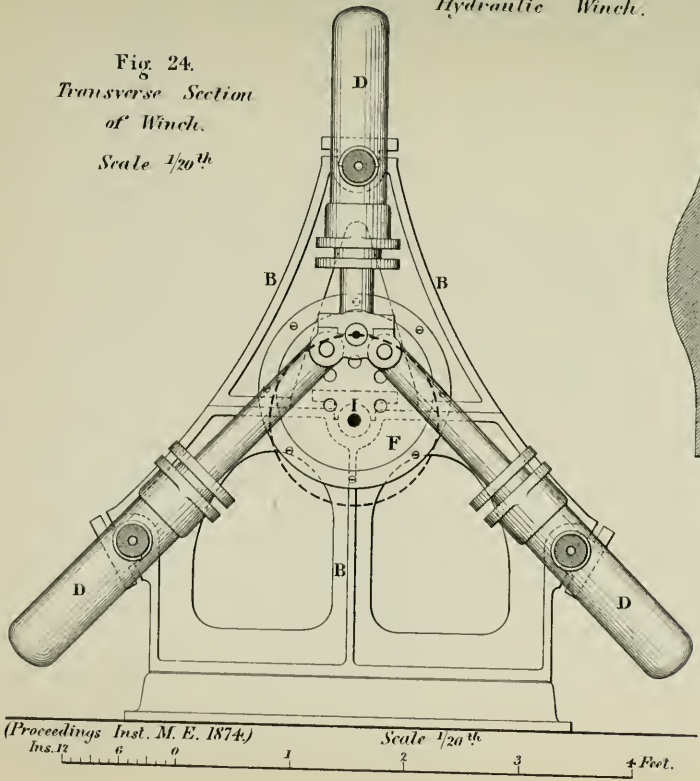


Fig. 24.
Transverse Section of Winch.
Scale 1/20th

(Proceedings Inst. M. E. 1874.)

Scale 1/20th

Ins. 12 6 0 1 2 3 4 Feet.

Cylindrical Valve.
Scale 1/4th

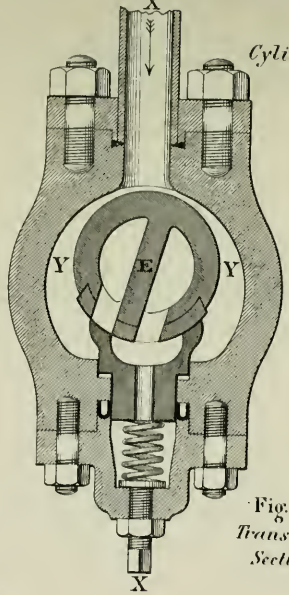


Fig. 25.
Transverse Section.

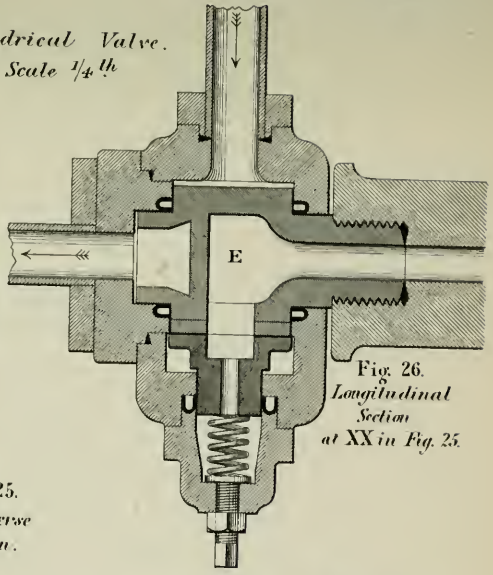
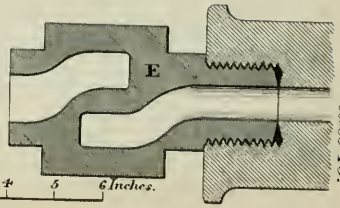


Fig. 26.
Longitudinal Section at XX in Fig. 25.

Fig. 27.
Longitudinal Section at YY in Fig. 25.



Scale 1/4th

0 1 2 3 4 5 6 Inches.

Plate 10.

Fig 28. *Hydraulic Swinging Jib.*

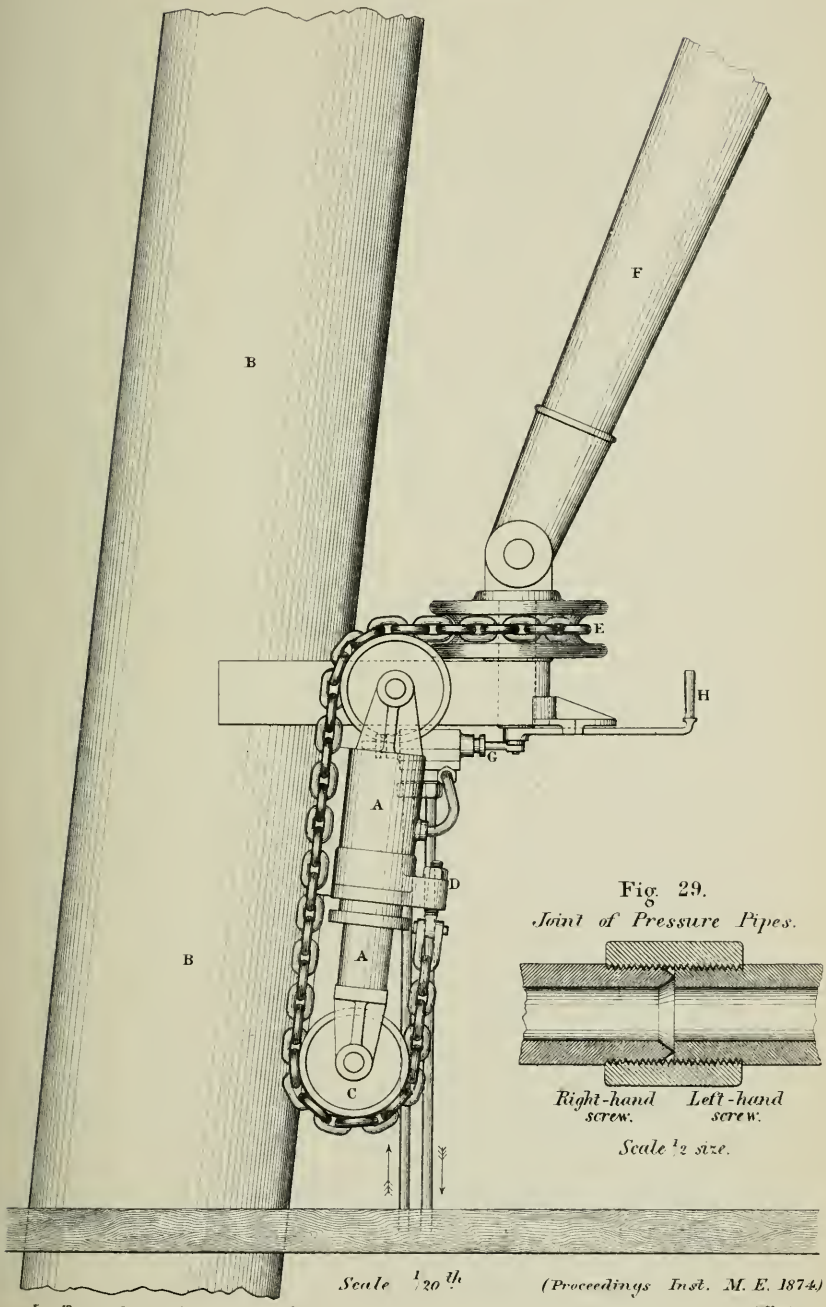


Fig. 29.
Joint of Pressure Pipes.

Scale 1/2 size.

1135

PROCEEDINGS.

29 January, 1874.

The Twenty-seventh Anniversary Meeting of the Members was held in the Lecture Theatre of the Midland Institute, Birmingham, on Thursday, 29th January, 1874; C. William Siemens, Esq., D.C.L., F.R.S., President, in the Chair.

The Minutes of the last General Meeting were read and confirmed.

The following Annual Report of the Council was then read:—

ANNUAL REPORT OF THE COUNCIL.

1874.

The Council on this occasion of the Twenty-seventh Anniversary present to the Members the annual statement of the position of the Institution and the progress during the past year.

The Financial statement of the affairs of the Institution for the year is satisfactory, showing that the balance on 31st December 1873 was £9317 1*s.* 0*d.*, after payment of the accounts due to that date. The greater portion of this balance is invested in £6000 London and North Western Railway 4 per cent. Debenture Stock, £1000 Midland Railway 4 per cent. Debenture Stock, and £1000 Great Western Railway 4 per cent. Debenture Stock, registered in the names of Mr. John Ramsbottom, Mr. Frederick J. Bramwell, and Mr. Sampson Lloyd, as interim trustees on behalf of the Institution. The Finance Committee have examined and checked the receipts and payments of the Institution for last year 1873, and report that the following Abstract of Receipts and Expenditure rendered by the Treasurer is correct. (*See Abstract appended.*)

The total number of Members of all classes in the Institution for last year is 956, of whom 4 are Honorary Life Members, 29 are Associates, and 28 are Graduates; 67 of the whole are resident in various foreign countries.

The following deceases of Members of the Institution have occurred during the past year 1873:—

Thomas Cabry,	York.
Thomas Clark,	Newcastle-on-Tyne.
Edward Crowe,	Middlesbrough.
Charles De Bergue,	London.
William John Forrest,	Ottawa, Canada.
Benjamin Gibbons,	Halesowen.
Thomas Greenwood,	Leeds.
Thomas Crump Hambling,	London.
John James,	Pontypool.
Matthew Kirtley,	Derby.
John Mackay,	Drogheda.
John Robinson McClean, M.P., F.R.S.,	London.
Alexander Samuelson,	London.
Thomas Swingler,	Derby.
Charles Troward,	London.

The following Donations to the Library of the Institution have been received during the past year, for which the Council have the pleasure of expressing their thanks to the Donors. They trust the Members generally will promote the formation of a good collection of Engineering Books, Drawings, and Models or Specimens of interest in the Institution, for the purpose of reference by the Members personally or by correspondence; and Members are requested to present copies of their Works to the Library of the Institution.

LIST OF DONATIONS TO THE LIBRARY.

On the Efficiency and Performance of Machine Tools, by Dr. E. Hartig; from the Royal Saxon Polytechnic School, Dresden.

Experimental enquiry into the Mechanical Properties of Fagersta Steel, by David Kirkaldy; from the author.

Observations on the Metalliferous Deposits of Cornwall, by William Jory Henwood, F.R.S., F.G.S.; from the author.

Two Addresses to the Royal Institution of Cornwall, by William Jory Henwood, F.R.S., F.G.S.; from the author.

Publications of the United States Geological Survey; from Dr. F. V. Hayden, United States Geologist.

The Sutro Tunnel and Railway to the Comstock Lode, Nevada, by Adolph Sutro; from the author.

Special Report on United States Immigration, by Edward Young, Ph. D.; from the author.

New South Wales, the oldest and richest of the Australian Colonies, by Charles Robinson; from Sir Charles Cowper.

Scientific Publications of the Royal University of Norway, Christiania; from the University.

Voies de Communication de la France, by M. Felix Lucas; from the Ecole des Ponts et Chaussées.

Description of the Models and Drawings exhibited by the French Ministry of Public Works at the Vienna Exhibition, 1873; from the Ecole des Ponts et Chaussées.

Catalogue des Galeries de l'Ecole des Ponts et Chaussées, Paris; from the Ecole.

History of the Ecole des Ponts et Chaussées, Paris; from the Ecole.

Some Applications of Theory to the Practice of Construction, by Col. H. Wray, R.E.; from the School of Military Engineering.

Lectures on the Manufacture, Use, and Testing of Gas for Illumination, by Dr. Pole; from the School of Military Engineering.

Lectures on the Chatham Dockyard Extension Works, by E. A. Bernays; from the School of Military Engineering.

Notes of Lectures on the use of certain Electrical Apparatus; from the School of Military Engineering.

Notes on the Building Trades and Building Construction, by Capt. H. C. Seddon, R.E.; from the School of Military Engineering.

Explosions in Coal Mines, by John Nixon; from the author.

On the recent Boiler Explosion at the Linthorpe Iron Works, Middlesbrough, by Jeremiah Head; from the author.

The Economy of Coal for Domestic purposes, by Edward B. Marten; from the author.

Safety of Permanent Way, by Christer P. Sandberg; from the author.

On a new method of Preventing Shock in Reversing Rolling Mills, by Jeremiah Head; from the author.

Abridgments and Indexes of British Patents; from the Commissioners of Patents.

Supplement to series of Letters Patent and Specifications, Nos. 12 and 13; from the Patent Office.

United States Patent Office Reports, 1869-71, 7 vols.; from the Commissioner.
Proceedings of the French Institution of Civil Engineers; from the Institution.
Journal of the French Society for the Encouragement of National Industry; from the Society.
Journal of the Hanover Architect and Engineer's Society; from the Society.
Journal of the Saxon Society of Engineers; from the Society.
Journal of the Norwegian Polytechnic Society; from the Society.
Transactions of the American Society of Civil Engineers; from the Society.
Report of the Bombay Mechanics' Institute; from the Institute.
Proceedings and Journal of the Asiatic Society of Bengal; from the Society.
Proceedings of the Institution of Civil Engineers; from the Institution.
Transactions of the North of England Institute of Mining Engineers; from the Institute.
Proceedings of the South Wales Institute of Engineers; from the Institute.
Transactions of the Institution of Engineers in Scotland; from the Institution.
Journal of the Iron and Steel Institute; from the Institute.
Transactions of the Society of Engineers, 1871; from the Society.
Proceedings of the Cleveland Institution of Engineers; from the Institution.
Transactions of the Chesterfield and Derbyshire Institute of Engineers; from the Institute.
Report of the British Association for the Advancement of Science; from the Association.
Transactions of the Institution of Naval Architects; from the Institution.
Transactions of the Institution of Surveyors; from the Institution.
Journal of the Royal United Service Institution; from the Institution.
Proceedings and Library Catalogue of the Royal Artillery Institution; from the Institution.
Journal of the Royal Agricultural Society of England, 9 vols. from 1865; from the Society.
Proceedings of the Royal Institution of Great Britain; from the Institution.
Transactions of the Royal Scottish Society of Arts; from the Society.
Proceedings of the Philosophical Society of Glasgow; from the Society.
Journal of the Liverpool Polytechnic Society; from the Society.
Journal of the Royal Cornwall Polytechnic Society; from the Society.
Journal of the Society of Arts; from the Society.
Reports of the Manchester Association for the Prevention of Steam Boiler Explosions; from Mr. Lavington E. Fletcher.
Report of the Manchester Boiler Insurance Company; from Mr. Robert B. Longridge.
Reports of the Midland Steam Boiler Association; from Mr. Edward B. Marten.
Report of the National Boiler Insurance Company; from Mr. Henry Hiller.

Beeton's Dictionary of Information in Science, Art, and Literature; from the Editor.
The Engineer; from the Editor.
Engineering; from the Editor.
Iron; from the Editor.
The Mining Journal; from the Editor.
The Railway Record; from the Editor.
Bust of the late Henry Maudslay; from Mr. Henry Maudslay.

The Papers brought before the meetings during the past year, and the discussions that took place upon them, have possessed much practical interest, and form a valuable addition to the Proceedings of the Institution. The Council request the aid and co-operation of the Members in carrying out the objects of the Institution and maintaining its advanced position, by contributing Papers on Engineering subjects that have come under their observation, and communicating the particulars and results of executed Works and practical experiments that may be serviceable and interesting to the Members; and they invite communications upon the subjects in the list appended, and other subjects advantageous to the Institution.

The following Papers have been read at the Meetings during the past year:—

Description of an improved apparatus for Working and Interlocking Railway Signals and Points; by Mr. William Baines.
On the Allen Governor and Throttle Valve for steam engines; by Mr. Frederick W. Kitson.
On Wenham's Heated-Air Engine; by Mr. Conrad W. Cooke.
On the Mining District of Cornwall and West Devon; by Mr. J. Henry Collins.
On the Mechanical Appliances used for Dressing Tin and Copper Ores in Cornwall; by Mr. Henry T. Ferguson.
Description of the Tin Stream Works in Restronguet Creek, near Truro; by Mr. Charles D. Taylor.
On the application of Portable Engines for Mining Purposes; by Mr. John Richardson.
Description of a Machine for Shaping the Models used in experiments on Forms of Ships; by Mr. William Froude, F.R.S.

Description of the Mechanical Scraper for Removing Incrustation in the Mains of the Torquay Water Works ; by Mr. John Little.

Description of the Bracket Chairs for Suspending Double-headed Rails on the West Cornwall Railway ; by Mr. James D. Sheriff.

On Tilghman's Sand-Blast Process, and its application for Cutting Stone &c.; by Mr. William E. Newton.

Description of a Wrought-Iron Construction of Observatory, for maintaining equality of internal and external temperature ; by Mr. Charles Clement Walker.

The Annual Meeting of the Institution last summer was held in Cornwall; and the Council have great pleasure in expressing their sense of the special kindness and valuable aid received on that occasion from the Committee of the Royal Cornwall Polytechnic Society, and the Honorary Local Secretaries, Mr. J. Henry Collins and Mr. Henry T. Ferguson, in the very excellent arrangements and the cordial and handsome reception that was given to the Members; and also from the proprietors of the mines and works that were so liberally thrown open for the inspection of the Members, and from the railway authorities in the special arrangements granted for the excursions. The Council refer with great satisfaction to the advantages arising from these Annual Meetings of the Institution in different localities, in consequence of the opportunities for visiting important Engineering and other Works on these occasions, and the facilities afforded for the personal communication of the Members in different districts.

In accordance with the recommendation of the Council in the last Aunual Report, a trial was made last year of holding the Spring Meeting of the Institution in London; and the result is considered by the Council to justify a repetition of the trial in the present year, which is accordingly proposed to be effected, with the view of making such arrangement permanent.

Considering the present available resources of the Institution, the Council intend to lay before a future Meeting a proposal for improving and extending its useful action.

The President, Vice-Presidents, and five of the Members of the Council in rotation, go out of office this day, according to the rules of the Institution; and the ballot taken at the present Meeting will show the election of the Officers and Council for the ensuing year.

SUBJECTS FOR PAPERS.

STEAM ENGINE BOILERS, particulars of construction—form and extent of heating surface—relative value of radiant surface and flue surface in effect and economy—cost—consumption of fuel—evaporation of water—pressure of steam—density and heat of steam—superheated steam, simple or mixed with common steam—combined air and steam—safety valves—water gauges—explosion of boilers, and means of prevention—strength and proportions of riveted joints, single and double riveting—comparative strength of drilled and punched plates—effects of heat on the metal of boilers, low-pressure and high-pressure—steel boilers—cast-iron boilers—welded boilers—small water-space boilers for specially high pressures—incrustation of boilers, and means of prevention—corrosion of boilers, and means of prevention—effects of surface condensers on the metal of boilers—evaporative power and economy of different kinds of fuel; coal, wood, charcoal, peat, coke, and artificial fuel—mechanical firing, moveable grates and smoke-consuming apparatus, facts to show the best plan, and results of working—plans for heating feed-water—mode of feeding—use of injector—circulation of water—self-acting feeding apparatus.

STEAM ENGINES—expansive force of steam, and best means of using it—power obtained by various plans—comparison of double and single-cylinder engines—combined engines—compound-cylinder engines—comparative advantages of direct-acting and beam engines—horizontal and vertical engines—condensing and non-condensing engines—construction and particulars of working of injection and surface condensers—ejector condenser—air-pumps—governors—throttle valves—bearings, &c.—improved expansion gear—indicator diagrams from engines, with details of useful effect, consumption of fuel, &c.—contributions of indicator diagrams for reference in the Institution.

PUMPING ENGINES, particulars of various constructions—Cornish engines, beam engines with crank and flywheel, direct-acting engines with and without flywheel—size of steam cylinder and degree of expansion—number and size of pumps, and strokes per minute—speed of piston—pressure upon pump—effective horse power and duty—comparison of double-acting and single-acting pumping engines—construction of pumps—plunger pumps—bucket pumps—details of different pump valves—india-rubber valves, durability and results of working—diagrams of lift of valves—application of pumps—fen-draining engines—comparative advantages of scoop wheels and centrifugal pumps, lifting trough, &c.—sewage pumping engines—details of pit work of pumping engines in mines.

BLAST ENGINES, best kind of engine—details of construction—pressure of blast, and means of regulation—construction of valves—improvements in blast cylinders—rotary blowing machines—indicator diagrams from steam cylinder, blast cylinder, and blast main.

MARINE ENGINES, power of engines in proportion to tonnage—different constructions of engines, compound-cylinder engines, trunk engines, oscillating engines—three-cylinder engines—use of steam jackets—dynamical effect compared with indicator diagrams—comparative economy and durability of different boilers, tubular boilers, flat-flue boilers, &c.—brine pumps, and means of preventing deposit—salinometers—weight of machinery, and boilers—speed obtained in different steamers, with particulars of construction of engines—screw propellers, particulars of different kinds, improvements in form and position, number of arms, material, means for unshipping, bearings, horse power applied, speed obtained, section of vessel—reaction propellers—governors and storm governors.

ROTARY ENGINES, particulars of construction and practical application—details of results of working.

LOCOMOTIVE ENGINES, particulars of construction, details of experiments, and results of working—economy of fuel—relative value and evaporative duty of coke and coal—consumption of smoke—use of wood—construction of spark arresters—heating surface, length and diameter of tubes—material of tubes—experiments on size of tubes and blast-pipe—construction of pistons, valves, expansion gear, &c.—balanced slide-valves—indicator diagrams—expenses of working and repairs—means of supplying water to tenders—locomotives for steep gradients and sharp curves—steam breaks, counterpressure steam break—distribution of weight on wheels.

AGRICULTURAL ENGINES, details of construction and results of working—duty obtained—application of machinery and steam power to agricultural purposes—barn machinery—field implements—traction engines, particulars

of performance and cost of work done—steam road rollers, particulars and results.

HOT-AIR ENGINES—engines worked by gas, or explosive compounds—electro-magnetic engines—particulars and results.

HYDRAULIC ENGINES, particulars of application and working—pressure of water—construction and arrangement of valves, relief valves—accumulator—hydraulic machinery—construction of joints—hydraulic rams.

WATER WHEELS, particulars of construction and dimensions—form and depth of buckets—head of water, velocity, percentage of power obtained—turbines, construction and practical application, power obtained, comparative effect and economy—transmission of power to distant points.

WIND MILLS, particulars of construction—number of sails, surface and form of sails—velocity, and power obtained—average number of days' work per annum.

CORN MILLS, particulars of improvements—power employed—application of steam power—results of working with an air blast and ring stones—crushing by rolls before grinding—stone-dressin machinery.

SUGAR MILLS, particulars of construction and working—results of application of the hydraulic press in place of rolls—application of steam and water for extracting the last portion of saccharine matter—construction and working of evaporating pans.

OIL MILLS, facts relating to construction and working, by stampers, by screw presses, and by hydraulic presses—particulars of crushing rollers and edge stones.

COTTON MILLS, information respecting the construction and arrangement of the machinery—power employed, and application of power—cotton presses, mode of construction and working, power employed—improvements in spinning, carding, and winding machinery, &c.

CALICO-PRINTING AND BLEACHING MACHINERY, particulars of improvements.

WOOL MACHINERY, carding, combing, roving, spinning, &c.

FLAX MACHINERY, manufacture of flax, china grass, and other fibrous materials, both in the natural length of staple and when cut.

WEAVING MACHINERY, for manufacture of different materials—improvements in looms, &c.

KNITTING MACHINERY, worked by hand or by power—particulars of improvements.

ROPE-MAKING MACHINERY—hemp and wire ropes, comparative strength, durability, and cost—steel wire ropes—transmission of power by ropes, percentage of loss, distance, wear of ropes, &c.

SAW MILLS, particulars of construction—mode of driving—power employed—particulars of work done—best speeds for vertical and circular saws—form of saw teeth—saw mills for cutting ship timbers—veneer saws—endless band saws.

WOOD-WORKING MACHINES, morticing, dovetailing, planing, rounding, and surfacing—copying machinery.

STONE-WORKING MACHINERY—cutting, planing, turning, and polishing machines.

GLASS MACHINERY—manufacture of plate and sheet glass—grinding and polishing machinery—construction of heating furnaces, annealing kilns, &c.

LATHES, PLANING, BORING, DRILLING, SLOTTING, AND SHAPING MACHINES, &c., particulars of improvements—description of new self-acting tools—engineers' tools—files and file-cutting machinery.

ROLLING MILLS, improvements in machinery for making iron and steel—mode of applying power—use of steam hammers—piling of iron—plates—fancy sections—arrangement and speed of rolls—length of bar rolled—manufacture of rolled girders—rolling of armour plates—reversing rolling mills.

STEAM HAMMERS, improvements in construction and application—friction hammers—air hammers.

RIVETING, PUNCHING, AND SHEARING MACHINES, worked by steam or hydraulic pressure—direct-acting and lever machines—portable machines—rivet-making machines—comparative strength of hand and machine riveting—plate-bending and flanging machines.

STAMPING AND COINING MACHINERY, particulars of improvements, &c.

LOCKS, and lock-making machinery—iron safes.

PAPER-MAKING AND PAPER-CUTTING MACHINES, new materials and results.

PRINTING MACHINES, particulars of improvements, &c.—machines for printing from engraved surfaces—type composing and distributing machines.

WATER PUMPS, facts relating to the best construction, means of working, and application—velocity of piston – construction, lift, and area of valves.

AIR PUMPS, facts relating to the best construction, means of working, and application—velocity of piston—construction, lift, and area of valves.

HYDRAULIC PRESSES, facts relating to the best construction, means of working, and application—economical limit of pressure.

ROTARY AND CENTRIFUGAL PUMPS, ditto ditto ditto.

FIRE ENGINES, hand and steam, ditto ditto ditto.

SLUICES AND SLUICE COCKS, worked by hand or hydraulic power, ditto.

CRANES—steam, hydraulic, and pneumatic cranes—travelling cranes.

LIFTS for raising railway wagons—hoists for warehouses, blast-furnaces, &c.—safety apparatus.

TOOTHED WHEELS, best construction and form of teeth—results of working—strength of iron and wood teeth—moulding by machinery.

DRIVING BELTS AND STRAPS, best make and material, leather, gutta-percha, vulcanised india-rubber, rope, wire, chain, &c.—comparative durability, adhesion, and results of working—power communicated by certain sizes—

frictional gearing, construction and driving power obtained—friction clutches—shafting and couplings.

DYNAMOMETERS, construction, application, and results of working.

PRESSURE GAUGES, for steam and water—varieties of construction—durability and results of working.

DECIMAL MEASUREMENT—application of decimal system of measurement to mechanical engineering work, drawing and construction of machinery, manufactures, &c.—construction of measuring instruments, gauges, &c.

STRENGTH OF MATERIALS, facts relating to experiments, and general details of testing.

GIRDERS OF CAST AND WROUGHT IRON, particulars of different constructions, and experiments on them—rolled girders—best forms and proportions of girders for different purposes—best mixture of metal—mixtures of wrought iron with cast.

DURABILITY OF TIMBER of various kinds—best plans for seasoning and preserving timber and cordage—results of various processes—comparative durability of timber in different situations—experiments on actual strength of timber.

CORROSION OF METALS by salt and fresh water, and by the atmosphere, &c.—facts relating to corrosion, and best means of prevention—means of keeping ships' bottoms clean—galvanic action, nature and preventives.

ALLOYS OF METALS, facts relating to different alloys.

FRICTION OF VARIOUS BODIES, facts relating to friction under ordinary circumstances—facts on increase of friction by reduction of surface in contact—friction of iron, brass, copper, tin, wood, &c.—proportion of weight to rubbing surface—best forms of journals, and construction of axleboxes—wood bearings—water axleboxes—lubrication, best materials, means of application, and results of practical trials—best plans for oil tests—friction breaks—friction of ropes.

IRON ROOFS, particulars of construction for different purposes—durability in various climates and situations—comparative cost, weight, and durability—roofs for slips of cast-iron, wrought-iron, timber, &c.—best construction, form, and materials—details of large roofs, and cost.

FIRE-PROOF BUILDINGS, particulars of construction—most efficient plan—results of trials—means of rendering timber &c. incombustible.

CHIMNEY STACKS of large size—particulars, form, mode of building, cheapest construction, &c.—force of draught, and temperature of current.

BRICKS, manufacture, durability, and strength—hollow bricks, fire bricks, and fire clay—perforated bricks, cost of manufacture, and advantages—dry-clay bricks—machines for brick-making—burning of bricks.

GAS WORKS—best form, size, and material for retorts—construction of retort ovens—quantity and quality of gas from different coals—oil gas, cheapest

mode of making—water gas, &c.—improvements in purifiers, condensers, and gasholders—wet and dry gas-meters—self-regulating meters—pressure of gas, gas exhauster—gas pipes, strength and durability, and construction of joints—proportionate diameter and length of gas mains, and velocity of the passage of gas—experiments on ditto, and on the friction of gas in mains, and loss of pressure—lighting railway trains with gas.

WATER WORKS, facts relating to—application of power, and economy of working—proportionate diameter and length of pipes—experiments on the discharge of water from pipes, and friction through pipes—incrustation in pipes, effect on delivery, and means of prevention or removal—strength and durability of pipes and construction of joints—penetration of frost in different climates—relative advantages of stand pipes and air vessels—sluices and self-actiug valves—relief valves—machinery for working sluices—water meters, construction and working.

WELL SINKING AND ARTESIAN WELLS, facts relating to—boring tools, construction and mode of using.

TUNNELLING MACHINES, particulars of construction, and results of working.

COFFERDAMS AND PILING, facts relating to construction—cast-iron sheet piling.

PIERS, fixed and floating, and pontoons—particulars of construction.

PILE DRIVING APPARATUS, particulars of improvements—use of steam power—particulars of working—weight of ram and height of fall, total number of blows required—vacuum piles—compressed air system—screw piles—pile shoes.

DREDGING MACHINES, particulars of improvements—application of dredging machines—power required and work done.

DIVING BELLS AND DIVING DRESSES, facts relating to the best construction.

LIGHTHOUSES, cast-iron and wrought-iron, ditto ditto.

SHIPS, iron and wood—details of construction—lines, tonnage, cost per ton—water ballast—steel masts and yards, and wire-rope rigging—comparative strength and advantage of iron and wood ships—arrangements for docking and repairing ships—steering gear—application of steam and hydraulic power to steering.

GUNS, cast-iron, wrought-iron, and steel—manufacture and proof—rifling—manufacture of shot and shells.

SMALL ARMS, machinery for manufacture of rifles and cartridges, &c.—breech-loading mechanism.

BLASTING, facts relating to blasting under water, and blasting generally—use of gun-cotton, dynamite, &c.—effects produced by large and small charges of powder—arrangement of charges.

MINING OPERATIONS, facts relating to mining—modes of working and proportionate yield—coal-cutting machines—rock-drilling machines—means of ventilating mines—use of ventilating machinery—safety lamps—lighting

mines by gas—drainage of mines—sinking pits—mode of raising materials —safety guides—winding machinery—hauling arrangements underground and at surface—stone-breaking machines—mode of breaking, pulverising, and dressing various descriptions of ores—coal-washing machinery.

BLAST FURNACES, shape and size—consumption of fuel—yield and quality of metal—pressure of blast—economy of working—improvements in manufacture of iron—comparative results of hot and cold blast—increased temperature of blast—construction and working of hot-blast stoves—pyrometers—construction of tuyeres—means and results of application of waste gas from close-topped and open-topped furnaces—preparation of materials for furnace, and mode of charging.

PUDDLING FURNACES, best forms and construction—gas furnaces—application of machinery to puddling.

SMELTING FURNACES, for reduction of copper, tin, and lead ores, &c.—best construction and modes of working.

HEATING FURNACES, best construction—consumption of fuel, and heat obtained.

CUPOLAS, construction and proportions—improvements in means of blowing—results of working, and economy of fuel.

CONVERTING FURNACES, construction of furnaces—manufacture of steel—casehardening, &c.—converting materials employed.

SMITHS' FORGES, best construction—size and material—power of blast—hot blast, &c.—construction of tuyeres.

BLOWING FANS, best construction, form of blades, &c.—facts relating to power employed and percentage of effect produced—pressure and quantity of air discharged—size and construction of air mains.

VENTILATING FANS for mines—mechanical ventilation and warming of public buildings.

COKE AND CHARCOAL, particulars of the best mode of making, and construction of ovens, &c.—open coking, mixtures of coal-slack and other materials—evaporative power of different varieties—peat, manufacture of compressed peat.

RAILWAYS, construction of permanent way—section of rails, and mode of manufacture—mode of testing rails—experiments on rails, deflection, deterioration, and comparative durability—material and form of sleepers, size, and distances—improvements in chairs, keys, and joint fastenings—permanent way for hot climates.

SWITCHES AND CROSSINGS, particulars of improvements, and results of working.

TURNTABLES, particulars of various constructions and improvements—engine turntables.

SIGNALS for stations and trains, and self-acting signals—interlocking apparatus for signals and points.

ELECTRIC TELEGRAPHS, improvements in construction and insulation—coating of wires—underground and submarine cables—mode of laying, and machinery employed.

RAILWAY CARRIAGES AND WAGONS, details of construction—proportion of dead weight.

BREAKS for carriages and wagons, best construction—self-acting breaks—continuous breaks—steam, air, and hydraulic breaks.

BUFFERS for carriages, &c., and station buffers—different constructions and materials.

COUPLINGS for carriages and wagons—self-acting couplings.

SPRINGS for carriages, &c.—buffing, bearing, and draw springs—range and deflection per ton—particulars of different constructions and materials, and results of working.

RAILWAY WHEELS, wrought-iron, cast-iron, and wood—particulars of different constructions, and results of working—comparative expense and durability—wrought-iron and steel tyres, comparative economy and results of working—mode of fixing tyres—manufacture of weldless tyres, and solid wrought-iron wheels.

RAILWAY AXLES, best description, form, material, and mode of manufacture—durability, and causes of fracture.

PREPARATION OF PAPERS.

The Papers to be written in the third person, on foolscap paper, on one side only of each page, leaving a clear margin of an inch width on the left edge. In the subjects of the papers, extracts from printed publications and questions of patent right or priority of invention are not admissible.

The Diagrams to be on a large scale and strongly coloured, so as to be clearly visible to the meeting at the time of reading the paper. Enlarged details to be added for the illustration of any particular portions, drawn full size or magnified, with the different parts strongly coloured in distinctive colours. Several explanatory diagrams drawn roughly to a large scale in dark pencil lines and strongly coloured are preferable to a few small-scale finished drawings. The scale of each diagram to be marked upon it.

INSTITUTION OF MECHANICAL ENGINEERS.

Abstract of Receipts and Expenditure,

For the year ending 31*st December* 1873.

Cr.			£	s.	d.
By Balance 31st Dec. 1872; Invested	6973	16 2			
In Bank	1195	0 3	8168	16	5
„ Subscriptions from 65 Members in arrear			195	0	0
„ do. 771 Members for 1873			2313	0	0
„ do. 25 Associates for 1873			75	0	0
„ do. 27 Graduates for 1873			54	0	0
„ do. 12 Members in advance			36	0	0
„ Entrance Fees from 67 New Members			134	0	0
„ do. 4 New Associates			8	0	0
„ do. 5 New Graduates			5	0	0
„ do. 1 Graduate transferred to Member			1	0	0
„ Sale of Extra Reports			48	9	0
„ Interest; From Bank	46	8 8			
On £7000 Stock at 4 p. c. one year, less inc. tax	275	12 6			
On £1000 Stock at 4 p. c. 146 days, less inc. tax	15	15 4	337	16	6
			£11,376	1	11

Dr.			£	s.	d.
To Printing and Engraving Reports of Proceedings	586	17 6			
Less Authors' copies of Papers, repaid	30	4 0	556	13	6
„ Stationery, Binding, Printing of Circulars, &c.			87	7	4
„ Office Expenses, Clerks, and Petty Disbursements			73	1	0
„ Coals, Gas, and Water			33	16	3
„ Expenses of Meetings			97	15	4
„ Fittings and Repairs			16	1	5
„ Travelling Expenses			69	5	2
„ Parcels			7	6	2
„ Postages			97	6	7
„ Salaries			898	8	4
„ Insurance			2	10	0
„ Rent and Taxes			119	9	10
Balance 31st Dec. 1873; Invested	7978	16 2			
In Bank	1338	4 10	9317	1	0
			£11,376	1	11

(Signed) CHARLES COCHRANE,
SAMPSON LLOYD,
WALTER MAY,
} Finance Committee.

29*th January*, 1874.

MEMOIRS

OF MEMBERS DECEASED IN 1873.

THOMAS CABRY was born on 6th June 1801, at the village of New York near Newcastle-on-Tyne; and having at an early age entered the engine factory of Mr. George Stephenson at Newcastle, then a very small concern, was in 1829 entrusted by him with the erection of stationary engines at numerous places in Great Britain and Ireland; and subsequently, having had charge of the erection of the stationary engines for working the incline of the Canterbury and Whitstable Railway, he was on the completion of the works in 1830 appointed Resident Engineer and Manager of that line. In 1836, on the recommendation of Mr. Stephenson, he was appointed Resident Engineer for the construction of the York and North Midland Railway; and on the completion of that line in 1839 he was appointed Engineer and Locomotive Superintendent. While holding the latter appointment he invented and carried out in practice a simple construction of expansion valve-gear for locomotives, which formed a step towards the link-motion subsequently invented. On the railway becoming merged in the North Eastern Railway in 1854 he ceased to hold the position of Locomotive Superintendent, and became Engineer of the southern division, embracing about 650 miles of railway, with a great number of timber bridges, some of them of large dimensions, the renewal of which with more permanent materials was successfully effected by Mr. Cabry. There are also several tunnels in which extensive renewals have been effected by him under considerable engineering difficulties; one at Leeds, nearly half a mile long, was increased 5 feet in width by taking down and rebuilding the side walls, leaving in the original crown of the arch. In consequence of a great portion of the ground being old coal workings and disintegrated shale, serious difficulties were

encountered, and the work of reconstruction occupied two years, from 1866 to 1868, during which the whole of the traffic was carried on through the tunnel without interruption upon a single line of rails. Failing health having led Mr. Cabry in 1870 to resign his situation, he was requested to retain it for some time longer, and accordingly did so until June 1871, when he finally retired, and his services were specially recognised by the directors. His death took place on 5th September 1873, in the seventy-third year of his age. He was a Member of the Institution from 1847, the year of its formation, and was at one time a member of the Council.

Thomas Clark was born on 4th May 1812 at Fatfield Colliery, Durham, and was apprenticed to Mr. Robert Jameson, founder, at the Teams, Durham, and completed his apprenticeship at Messrs. Hawks, Crawshay and Sons' Iron Works, Gateshead. In 1836 he took charge of Mr. John Elym's Ouseburn Foundry, Newcastle-on-Tyne; and in 1843 of the iron works of the Derwent Co., for whom he laid out the Crook Hall blast furnaces &c. He afterwards succeeded Mr. Jameson at Messrs. Hawks, Crawshay and Sons' Iron Works, where he made personally the experiments for the late Mr. Robert Stephenson in connection with the metal for the castings for the High Level Bridge over the river Tyne; and to him is attributed the credit of first making large dry-sand castings. In 1852 he commenced business at Low Elswick as a founder, afterwards adding that of marine engine builder. While so engaged he took charge in 1859 of the foundry and subsequently of the blast furnaces at the Elswick Works. His death took place on 15th August 1873, in the sixty-second year of his age. He became a Member of the Institution in 1869.

Edward Crowe was born on 14th January 1829 at Boulogne, and after studying in the engineering department of King's College, London, was engaged under the late Sir William Cubitt upon the Great Northern Railway. In 1849 he entered the works of Messrs. R. and W. Hawthorn, Newcastle-on-Tyne, and in 1852 was engaged in the workshops of the Great Northern Railway at

Boston, and afterwards in the drawing office of the Eastern Counties Railway at Stratford. During 1854 and 1855 he was in the works of Messrs. Fox, Henderson and Co. at Smethwick, and Messrs. Cochrane and Co. at Woodside. In 1856 he succeeded Mr. John Head as Engineer to the Warsaw Water Works, where he remained till 1862, and then returned to England. In 1864 he became the Engineer to the Tees Side Iron Works, Middlesbrough, of Messrs. Hopkins, Gilkes and Co., with whom he remained until his death, which took place on 20th December 1873 after a short illness, in the forty-fifth year of his age. During the past two years he had been busily engaged in striving to overcome the difficulties of mechanical puddling. He was also concerned in the establishment in 1870 of the Imperial Iron Works, Middlesbrough, of Messrs. Jackson, Gill and Co., in which he became a partner. He was a Member of the Institution from 1864.

Charles De Bergue was born at Kensington in 1807 of French parentage, and from his earliest years evinced a remarkable talent for mechanics. When quite a boy he invented machinery of an ingenious description for making the reeds of weaving looms, and worked it to great profit. On the restoration of the Bourbons he accompanied his family to Paris; and his father having, in connection with several French noblemen, opened an engineering establishment there, he was able to exercise freely his taste for mechanical engineering. In 1836 he returned to settle in England, and was the inventor of several valuable machine-tools now in use at many large works both in England and abroad. He was the proprietor of engineering works both at Manchester and Cardiff, where he carried on an extensive business in the manufacture of bridges and of the machines used in their construction; his designs for bridges specially aimed at uniting strength with lightness of construction. He invented a new system of iron permanent way, which has been successfully in use for many years in Spain and elsewhere; also railway buffers, a moulding table, punching, shearing, and riveting machines, with other useful engineers' tools, including a machine for making rivets, of which a description was given at

the Institution (see Proceedings Inst. M. E. 1861 page 212). His death occurred on 10th April 1873 at the age of sixty-five, from softening of the brain, after a painful and protracted illness of more than two years. He became a Member of the Institution in 1857.

William John Forrest was born at Annan in Dumfriesshire on 18th July 1828, and served his apprenticeship with Messrs. McCallum and Dundas, civil engineers of Edinburgh, by whom he was employed on the survey of the Ayrshire and Galloway Railway and on the construction of the Edinburgh branch of the Caledonian Railway. In January 1852 he went to Canada, where he was appointed one of the assistant engineers of the Great Western Railway of Canada, then in course of construction. In 1853 he was appointed chief assistant to Mr. James C. Street, who superintended the construction of the Hamilton and Toronto Railway. On the completion of this railway in 1856, for which Mr. Forrest had prepared all the working plans, he was employed for upwards of two years as chief assistant on the surveys and plans of the projected Niagara and Detroit Rivers Railway, of which Mr. Street was the Chief Engineer. Towards the end of 1859 he returned to England, and in 1863 became chief assistant to Messrs. Street and Marmont in London, with whom he continued until the death of Mr. Street in April 1867. He then established himself in practice on his own account till the summer of 1869, when he returned to Canada, and was engaged as chief assistant to Mr. Sandford Fleming, the Engineer-in-Chief of the Intercolonial Railway, his principal duties being to superintend under Mr. Fleming the designs and working plans of the numerous and varied structures in stone and iron required for that railway. This situation he continued to hold till the time of his death, which took place on 9th September 1873, in the forty-sixth year of his age, his health having been impaired by severe illness some months previously. He became a Member of the Institution in 1871.

Benjamin Gibbons, one of the oldest of the Ironmasters in South Staffordshire, belonged to one of the families earliest engaged in the

iron trade in that district, being a younger son of Mr. Thomas Gibbons of The Oaks, Tettenhall, Wolverhampton. He was born on 4th August 1783, and thus at the date of his decease, 21st April 1873, had nearly completed his ninetieth year. After being educated at the grammar schools of Wolverhampton and Birmingham, he acquired his first knowledge of business in the iron works at Cradley, and at the Level, Brierley Hill, belonging to his uncle of the same name. He was afterwards engaged in business with his eldest brother John and his younger brother Thomas at the Corbyn's Hall Collieries and Blast Furnaces, which were built by them about 1824 on their Corbyn's Hall estate near Dudley; and subsequently with his cousin, Mr. William Gibbons, at the Level New Furnaces, which he afterwards carried on alone. In his later years he resided at Hill Hampton House near Stourport, until 1865, when he became proprietor of Shenstone's estate at the Leasowes, Halesowen, where he was resident at the time of his death. He was a magistrate for the county of Stafford. He became a Member of the Institution in 1848, and gave a description of an early pneumatic lift which he had erected for charging blast furnaces at the Corbyn's Hall New Furnaces (see Proceedings Inst. M. E. July 1849); and also contributed a paper on the ventilation of mines, more particularly in reference to the Thick or Ten-Yard coal of the South Staffordshire district (see Proceedings Inst. M. E. April 1851).

Thomas Greenwood was born in 1807 at Gildersome near Leeds, and after serving some years in his father's machine shop he removed to Leeds about 1833, and went into business with his brother as machine and tool makers; but on his brother's death he became draughtsman and traveller with Messrs. S. and J. Whitham of Leeds. In 1843 he entered the works of the late Sir Peter Fairbairn, Wellington Foundry, Leeds, and soon after became practical manager of those works, in which in 1848 he and Mr. Batley became partners, and remained there until 1856. Mr. Greenwood and Mr. Batley then commenced business together at the Albion Foundry, East Street, Leeds, and in 1860 erected the

large Albion Works in Armley Road, Leeds. He was a thorough practical mechanic of very inventive genius and quick appreciation. His productions contributed greatly to the progress of the flax and silk manufactures, and in 1865 he gave a paper to the Institution on machinery employed in the preparation and spinning of flax (see Proceedings Inst. M. E. 1865 page 103). His firm were also largely employed by the British and many Foreign governments as makers of machinery for the manufacture of war material, in which capacity he was very successful and rendered great services to his country. He successfully competed with the most celebrated and experienced American tool makers in the manufacture of interchangeable small-arms machinery for the British and other European governments, and thereby he secured for this country a new branch of machine making. In connection with this subject he contributed two papers to the Institution, on machinery for the manufacture of gunstocks and of the Boxer cartridges (see Proceedings Inst. M. E. 1862 page 328 and 1868 page 105). He became a Member of the Institution in 1858, and was on the Council from 1868 to the time of his death, which took place on 9th February 1873, at his temporary residence at Gipsy Hill near London, in the sixty-sixth year of his age.

Thomas Crump Hambling was born at East Dereham, Norfolk, on 25th September 1835, and after serving his apprenticeship to Messrs. Ransome and Sims at Ipswich, became manager of the works of Mr. J. H. Porter at Birmingham and Tividale, for whom he went out to Spain and superintended the erection of several lighthouses under difficult and sometimes dangerous circumstances. He was afterwards engaged by Mr. Robert C. May in London, until he set up in practice there for himself in 1869 as a consulting engineer. He became a Member of the Institution in 1869. His death took place on 14th March 1873, in the thirty-eighth year of his age.

John James was born at Blaina in 1825, and was at first employed at the Blaina Iron Works. Afterwards he was for many years manager of the Ebbw Vale Iron Co.'s mills and forges

at Victoria and Ebbw Vale. In 1870 he relinquished this position, and joined the partnership of the Pontypool Iron and Tinplate Co., where he continued until his death, which took place on 4th November 1873. He became a Member of the Institution in 1868.

Matthew Kirtley was born on 6th February 1813 at Tanfield near Newcastle-on-Tyne, and up to the age of about thirteen was engaged under his father, who was a viewer in one of the collieries there. He then obtained employment under Mr. George Stephenson on the Stockton and Darlington Railway, both in the shops and on the engines; after which he was for a short time on the Liverpool and Manchester Railway. He was next engaged under Mr. Robert Stephenson at the London end of the London and Birmingham Railway, and was stationed at Watford, and drove the first locomotive which entered London. About 1837 he was appointed to the position of locomotive foreman of the running shed at Hampton; and in 1839, on the opening of the Birmingham and Derby Railway, he was selected as the Locomotive Superintendent; on the amalgamation of this line with the North Midland and Midland Counties in 1844, he became Locomotive Superintendent of the new Midland Railway thus formed. The engine-building and repairing shops at Derby and at the other principal stations on the Midland Railway were planned and their erection superintended by him; and the whole of the engines and rolling stock were built from his plans and under his direction. He was one of the original Members of the Institution at its formation in 1847, and was also for several years a member of the Council. He died on 24th May 1873, in the sixty-first year of his age, after suffering from illness for about a year.

John Mackay was born at Glasgow, and in the year 1828 went to Drogheda in charge of a new steam dredger, which he steamed over from Glasgow. After working the dredger for some time, he became connected with a small foundry in Drogheda, which under his superintendence grew into an establishment

of some importance, known as the Drogheda Iron Works, where locomotive engines, and marine engines and boilers for the Channel steamers were manufactured in considerable numbers, and some of the best work in Ireland was produced. About 1858 he retired from these works, and practised as a consulting engineer to the time of his death, which took place on 26th July 1873, at the age of about seventy-five. He became a Member of the Institution in 1856.

John Robinson McClean, M.P., was born at Belfast on 21st March 1813, and educated at the Royal Academical Institution in that town; and in 1834 went to Glasgow University to study engineering. In 1837 he entered the office of Messrs. Walker and Burges, Westminster, and was more or less connected with the various works undertaken by Mr. James Walker until 1844, when he established himself independently as a civil engineer; at the same time he became Engineer-in-chief of the Furness Railways, and was also connected with other principal public works in that district, including the Barrow harbour works and graving docks. In 1849 he sent in competitive plans to the Metropolitan Commissioners of Sewers for the drainage of London on both sides of the Thames, and his scheme was pronounced by the Commissioners to be the best conceived and most practicable of those submitted. In the same year he took into partnership Mr. F. C. Stileman, with whom he engaged in the construction of the South Staffordshire Railway, the Birmingham Wolverhampton and Dudley Railway, the Staffordshire and Worcestershire Canal reservoirs, and the South Staffordshire Water Works supplying water from Lichfield to a very extensive district. He was also consulting engineer to numerous other public works and companies in this country and abroad; and in 1855 was invited to visit Egypt, and report upon the practicability of uniting the Mediterranean and the Red Sea by a ship canal, and upon the barrage of the Nile, and other works. After the death of Mr. James Walker in 1862 he was appointed Government Engineer to the harbours of Dover, Alderney, and St. Catherine's, Jersey, and to the Plymouth

breakwater and fort. For many years he was the sole lessee of the South Staffordshire Railway, and in that capacity took a very prominent part in developing the mineral and agricultural resources of the Cannock Chase district, in which he was a large holder of mining property. He was President of the Institution of Civil Engineers for the years 1864 and 1865. He was one of the Members of Parliament for East Staffordshire from 1868 to the time of his death, which took place on 13th July 1873, in the sixty-first year of his age, after an illness of several months. He was a Member of this Institution from the commencement in 1847, and for some years also a member of the Council.

Alexander Samuelson was born at Hamburg on 20th July 1827, and at a very early age came to Hull. When about fourteen years of age, he was apprenticed to Messrs. Jones and Potts of Newton-le-Willows, and subsequently completed his apprenticeship with Messrs. Bury, Curtis and Kennedy at Liverpool; he then became draughtsman to Messrs. Nasmyth and Co. of Patricroft, and subsequently to Messrs. Boulton and Watt of Birmingham. He afterwards went for a short time to Tours in France, to assist his eldest brother, Mr. Bernhard Samuelson, in the management of some railway works, and in 1852 he joined his brother, Mr. Martin Samuelson, in extensive engineering and shipbuilding works at Hull; but in 1861, his health having failed through the labour incurred in the management, he left the firm and established himself in London as a consulting engineer, at first in partnership and from 1866 on his own account. This branch of the profession he followed successfully until his death on 5th September 1873, at the age of forty-six. He became a Member of the Institution in 1857, and in 1858 contributed a paper on oil-mill machinery (see Proceedings Inst. M. E. 1858 page 27).

Thomas Swingler was born at Leicester in 1820, and after having been engaged for some years as a workman upon the railway from Syston to Peterborough and upon other railway works in and about Leicester, he removed to Derby, and continued

for some years employed upon the Midland Railway under Mr. W. H. Barlow. He then entered into partnership with Messrs. Marsden and Taylor, engineers, Derby, and some time afterwards on a dissolution taking place he commenced business upon his own account at the Victoria Iron Works, Litchurch, Derby; these works he carried on successfully until their amalgamation in 1868 with the Railway Iron Works of Messrs. Eastwood and Sons, the joint concern of Messrs. Eastwood Swingler and Co. employing over 800 hands. His death took place suddenly from erysipelas on 4th November 1873, in the fifty-fourth year of his age. He became a Member of the Institution in 1859.

Charles Troward was born at Torre, Torquay, on 8th January 1829. In 1848 he became the pupil of Mr. Archibald Sturrock in the locomotive works of the Great Western Railway at Swindon, and afterwards on the Great Northern Railway. He was then appointed to the locomotive works at Boston, and was subsequently removed to Doncaster, where he remained until 1867, when the position he had held of District Locomotive Superintendent terminated in consequence of a change in the working arrangements. He constructed a binocular telescope of his own invention, which was exhibited and received a prize. He died in London on 26th November 1873, at the age of forty-four, his health having been failing for some years previously. He became a Member of the Institution in 1862.

The CHAIRMAN moved that the Report of the Council be received and adopted, which was passed.

The CHAIRMAN announced that the Ballot Lists had been duly opened, and the following Officers and Members of Council were found to be elected for the ensuing year :—

PRESIDENT.

FREDERICK JOSEPH BRAMWELL, F.R.S., London.

VICE-PRESIDENTS.

I. LOWTHIAN BELL, ... Newcastle-on-Tyne.
THOMAS HAWKSLEY, ... London.
JOHN HICK, M.P., ... Bolton.
WILLIAM MENELAUS, ... Dowlais.
JOHN NAPIER, ... Glasgow.
JOHN ROBINSON, ... Manchester.

COUNCIL.

JOSEPH ARMSTRONG, ... Swindon.
HENRY BESSEMER, ... London.
WILLIAM CLAY, ... Liverpool.
CHARLES COCHRANE, ... Dudley.
EDWARD A. COWPER, ... London.
JEREMIAH HEAD, ... Middlesbrough.
PERCY G. B. WESTMACOTT, . . . Newcastle-on-Tyne.

PAST-PRESIDENTS.

Ex-officio permanent Members of Council.

SIR WILLIAM G. ARMSTRONG, C.B., D.C.L., LL.D., F.R.S., . . Newcastle-on-Tyne.
SIR WILLIAM FAIRBAIRN, Bart., LL.D., F.R.S., ... Manchester.
JAMES KENNEDY, ... Liverpool.
ROBERT NAPIER, ... Glasgow.
JOHN PENN, F.R.S., ... London.
JOHN RAMSBOTTOM, ... Manchester.
C. WILLIAM SIEMENS, D.C.L., F.R.S., London.
SIR JOSEPH WHITWORTH, Bart., D.C.L., LL.D., F.R.S., . . Manchester.

COUNCIL.

Members of Council remaining in office.

Charles Edwards Amos,	London.
John Anderson, LL.D.,	London.
Edgar Gilkes,	Middlesbrough.
Frederick W. Kitson,	Leeds.
Sampson Lloyd,	Wednesbury.
Walter May,	Birmingham.
Charles P. Stewart,	Manchester.
Francis W. Webb,	Crewe.

The following New Members were also declared to be elected:—

MEMBERS.

David Archer,	Birmingham.
William Cooper,	Hull.
Holmes Hird,	Burton-on-Trent.
George Peaker,	Kirkee, India.
William Henry Prosser,	London.
Herbert Rake,	Swansea.
John Alexander George Ross,	Newcastle-on-Tyne.
Henry Enfield Taylor,	Aberystwith.
Joseph Twibill,	Manchester.
Arthur John Whalley,	Truro.

GRADUATES.

Frank Allen,	Alexandria.
Henry Hedley,	Derby.
Thomas Hedley,	Derby.

The Chairman said he was sorry to have to announce the absence of the President elect, Mr. Bramwell, who had been most unexpectedly summoned to Egypt. A letter from Mr. Bramwell was read, expressing his great regret that he was thus prevented from attending the meeting.

On the motion of Mr. A. Paget seconded by Mr. H. Woods, the particulars were given of the attendances at the meetings during the last two years: at Birmingham in May 1872, 34 members and 20 visitors; in October 1872, 52 members and 34 visitors; in January 1873, 60 members and 18 visitors; in October 1873, 28 members and 17 visitors; and at London in May 1873, 125 members and 60 visitors.

Mr. A. PAGET then moved: That as the attendance at the last spring meeting in London was more than three times the average attendance at the meetings in Birmingham the council be requested to hold other future meetings in London in addition to the spring meeting, with a view to decide whether London is or is not a more convenient place for the meetings than Birmingham; and to give the council power to do this, the Rules be altered by adding the words "or London" after the word "Birmingham" in the rule "there are to be four general meetings in each year, three to be held in Birmingham." He thought that the attendance at the meetings in Birmingham was very small, and that with the large number of 950 members now in the institution there should be a greater average attendance at the meetings than at present, and there would be a considerably larger attendance at meetings held in London. The one experiment already tried had been eminently successful, and he was glad it had been decided by the council to hold the next spring meeting in London, in order to ascertain whether that was a more convenient place. When the institution was founded twenty-seven years ago it was very possible that Birmingham might have been the more generally accessible position, but the case was altered by the present rapid and frequent railway communication to London, and there was also the consideration that many members had frequently occasion to be in London on other business. He thought an institution of such importance, which was the leading institution in the country for mechanical engineers, should hold more of its meetings in the metropolis; and although possibly a few of the present members at Birmingham might be lost if such a change were made, he was confident an increase of members in London to a much greater

extent would be obtained, and it would then make the institution more truly a national one. London would also be preferable for carrying on the business of the institution, on account of there being many more members of the council there than at Birmingham, and he thought the usefulness and interest of the institution would be advanced by a removal to London, and there would be more frequent council meetings there; also that there would be a wish on the part of many provincial societies to affiliate themselves with this institution. He was not however proposing such a removal at present, but only that more of the meetings should be held in London in order to test the question more fully.

Mr. E. Jeffreys seconded the motion, and felt sure it would meet the wishes of a large number of the members.

Mr. J. Robinson thought that there was another question that should also be considered: Whether it would not be desirable in the interest of the institution that meetings should be occasionally held in Manchester as well as in London. Although many of the members whose business was not only mechanical but commercial, would find London a very convenient centre for holding meetings, it had to be borne in mind that a great many members were mechanical engineers engaged in works, who might not be able to make so long a journey for the purpose. He thought there was a decided objection to London absorbing the institutions of the whole country, and that it would be prejudicial to the interest of this institution for it to be removed either to London or to Manchester, the latter of which had once been suggested. But he thought that Manchester might fairly be said to be as much a metropolis as London, as regards mechanical engineering, and that meetings of the institution in the northern metropolis would be likely to have as good an attendance as meetings in the southern metropolis. With the view of affording the means of testing this, he should have given notice, if he had been present at the last meeting, for proposing the addition in the rules of the words "or Manchester," as well as "or London," and he thought that it was desirable in the interests of the institution that opportunity should be afforded for such a trial to be made, and he therefore proposed to bring the question forward at the next anniversary meeting.

Mr. A. B. Brown concurred in the suggestion about Manchester, and thought that as there were a large number of members in Scotland and the North, it would be a very long journey to require them to go to London for the meetings, and as Glasgow was a large centre of mechanical engineering that name might also be proposed to be added to the places for meeting.

Mr. W. L. Wise understood the main object of the motion was to ascertain whether London would be the most convenient place for the head quarters of the institution; the greater number of meetings would no doubt be held wherever the head quarters were situated, but he thought it was certainly desirable for a portion of the meetings to be held in some of the leading manufacturing centres of the country, and the motion would not interfere with such a course.

Mr. S. Lloyd remarked that the comparative attendance at a meeting in London in the spring could not be taken as an average, as at that season there were many members up there from the country from other causes. As regarded London, he believed there were many advantages connected with it, and so there were with Manchester; but Birmingham as the old centre of the institution had also advantages.

Mr. A. Paget considered also that a spring meeting alone in London did not afford a fair comparison, and thought meetings at other times of the year should also be tried there, in order to obtain a correct comparison of attendance; and if the result then was not favourable to London, he should consider it to dispose of the question. He did not see any objection to other meetings being held at Manchester or Glasgow, and if the proposal that had been named were made at the next anniversary meeting, to add the word Manchester, he should cordially support it; he only wished more London meetings in the year to be tried, in order to ascertain whether that was a more convenient centre than Birmingham or not.

The Chairman suggested that as it was already arranged to make trial of a London meeting again this year, it might be preferable to defer the consideration of holding additional meetings

in London until next year, when it appeared the question of a meeting at Manchester would also be brought under consideration.

Mr. W. W. Hulse thought that meetings at Manchester would lead to a further desire to include Glasgow, Newcastle, Leeds, and other places, and that the right course would be to have a London centre for the institution, with local branches over the country. He considered at least two meetings in the year should be held in London, in order to arrive at a fair comparison in regard to attendance, and proposed the spring meeting and the January meeting to be held in London.

Mr. P. D. Bennett thought the motion really contemplated a removal of the institution to London, and he considered any proposal to transplant an old established and successful institution was very undesirable, and that a removal of the institution to London would be injurious to its interests, and might alienate some of its original supporters; the institution had grown from infancy to maturity in its present position, and any change of locality was he thought very unadvisable, and not in the interests of the institution; he considered moreover a removal to London would bring it into antagonism with other institutions.

Mr. E. A. Cowper remarked that the institution had now grown to such importance as the special mechanical institution of the country, that it was necessary to take care it should thoroughly maintain that position, and to consider how it might confer the greatest benefit. He thought it would not be good for the institution to become a travelling society like the British Association, which could not be found for reference at any other part of the year than at the time of their meetings; and it was essential for the institution to have a permanent centre, that members might have the advantage of a library of reference, and to afford the means of further extending its usefulness. He was not opposed to the proposal to try the experiment of holding several further meetings in London, with the view of seeing whether it would be more desirable to make the head quarters there.

Mr. C. C. Walker understood the object of the motion was not to remove the institution to London, but to endeavour to ascertain

whether its usefulness could be increased by holding more of the meetings in London.

Mr. T. Hawksley observed that although the question before the meeting was only that of holding more meetings each year in London than the one for which there was at present provision in the rules, this really involved the further questions not only of a removal of the institution to London but also of an increase of the number of meetings in each year; because if more meetings were held in London there could scarcely be any in Birmingham and elsewhere, unless the present number were increased. These were questions of great importance for the welfare of the institution, and required a more careful and complete consideration than could be given in discussion at the present meeting; and he suggested that they would be best dealt with by being fully gone into by the council and reported upon by them for the consideration of the members at another meeting, either ordinary or special.

Mr. A. Paget pointed out that if the present rules were not altered the council would not have the power of holding other meetings in London than the spring one.

Mr. C. Cochrane suggested that the first part of the proposed resolution be omitted, which would then simply give power to the council to hold other meetings of the institution in London, as might be found desirable.

The following resolution was then passed: That the words "or London" be added after the word "Birmingham" in the rule "there are to be four general meetings in each year, three to be held in Birmingham."

The following paper was then read:—

ON HYDRAULIC MACHINERY FOR STEERING, REVERSING, AND DISCHARGING CARGO &c. IN STEAMSHIPS.

By Mr. ANDREW BETTS BROWN, of Edinburgh.

The application of Hydraulic Machinery to the various purposes requiring power on board steamships (independently of the propelling power) is a comparatively recent step; and in the writer's opinion it will be found to have important advantages over steam power for such purposes. There is a large amount of work of great importance to be done on board ship, such as loading and discharging cargo, hoisting the anchor and sails, warping the ship into dock, steering, stoking, discharging ashes &c., for all of which hydraulic power is especially deserving of consideration.

Taking for instance a transatlantic mail steamer carrying 2000 to 3000 tons of cargo as well as passengers, it is of the utmost consequence that having made a fast passage she should be expeditiously discharged, and receive her outward freight for getting away again immediately. The actual case however is that the cargo is discharged by means of four or five noisy steam-winches, which though rattling away at a piston speed of nearly 1000 feet per minute, and consequently involving great wear and tear and cost of repairs, are not able to raise the load out of the hold faster than about 100 feet per minute. The use of steam winches on board ship is also found to be attended with a great objection from the constant leakages at the joints to which the long lines of steam pipes are liable, in consequence of their frequent expansion and contraction when alternately hot and cold; and they are also liable frequently to be burst by the concussion of condensed water at their extremities, and in cold climates by the effect of frost. The same objections also apply to steam engines for the purposes of steering, anchor hoisting, &c.; and the requirements of the case can only be met satisfactorily by the total banishment from shipboard of all

steam engines and steam pipes outside the main engine-room, and of all toothed gearing and mechanism working at high speed.

In the application of hydraulic power to these purposes, motive power in the form of a steam pumping engine must of course be used; but the proper place for such a machine is in the engine room, where it can be attended by skilled mechanics. With a constant water pressure of 800 lbs. per square inch, pipes of comparatively small size suffice to convey the power to the small cylinders and rams, which without any purchase gearing are found sufficiently powerful and expeditious to meet all the wants in steering the ship, reversing the main engines, raising anchor, hoisting cargo, discharging ashes, swinging jib, &c. The following mechanism has been designed by the writer to meet the above requirements.

Steam Accumulator.—The motive power is supplied by a pair of ordinary double-acting pumping engines, shown at A A in Fig. 1, Plate 1, which are in connection with a Steam Accumulator B. This consists of a large steam cylinder 36 inches diameter, fitted with a piston C, and the piston-rod D forms the ram of a hydraulic cylinder E, having 1-15th the area of the steam-cylinder B, so that 50 lbs. per inch steam pressure gives a water pressure of 750 lbs. per inch in the hydraulic cylinder (less the amount of friction). Steam is admitted to the top of the accumulator cylinder at F, from the ordinary donkey boiler or the main boilers; and the pumping engines are supplied by a branch G from the opposite side of the cylinder, and force the water from their pumps into the hydraulic cylinder at H. The bottom of the accumulator cylinder B is open constantly to the exhaust K. When steam is turned on to the accumulator, the engines start at the same time pumping up the hydraulic ram D, and they continue working until the steam-piston rises high enough to close the steam-pipe orifice G. The engines then stop; but when water is drawn from the accumulator by the action of the hydraulic machinery, the steam-piston descends, maintaining the pressure of 750 lbs. per inch upon the water; at the same time by opening the steam-pipe G it starts the engines again, and so the accumulator is replenished.

The steam-piston of the accumulator is somewhat novel in the mode employed for making the hemp packing self-tightening, as shown to a larger scale in the section, Fig. 2. The junk ring is in one piece with the piston cover J, fitting loosely upon the centre boss of the piston; then if the hemp packing is tight, the inside and outside of the ring are in equilibrum, and there is therefore only a pressure on the annular area of the packing; but if the packing leaks more than the slackness of the small boss of the piston-end can pass, then the equilibrium is disturbed and the junk ring is pressed down and tightens the packing.

This steam accumulator can be placed either vertically or horizontally, as may be most convenient; and it is usually laid with its engines upon the main engine-room floor. The packing of the accumulator piston and the hydraulic ram does not require any attention during at least a year's work; and the engines being automatically stopped and started require no attention beyond ordinary oiling. Although a water pressure of 700 to 800 lbs. per square inch is usually maintained for working at full power, the pressure can be reduced to 200 lbs. by using a lower steam pressure, whenever doing exceptionally light work.

Hydraulic Reversing Gear.—In Plates 2 and 3 is shown the Hydraulic Reversing Gear, which has been applied to the steamship "Mikado" of 3000 tons, and is similar to that in use in the "Cheshire" and the "Birkenhead" ferryboats at Liverpool; these latter boats have each two pairs of engines, which are easily reversed by one man by means of this hydraulic gear.

The apparatus consists of two hydraulic single-acting cylinders A A, Figs. 3 and 4, having rams $4\frac{3}{4}$ inches diameter and 19 inches stroke, coupled together and working in opposite directions, and connected by side rods B from the boss C to the weigh-shaft lever D. In the working of the apparatus, water from the accumulator is admitted to either of the cylinders as required, by opening the slide-valve E by means of the reversing handle F, which is centred at G, and has a detent rod and quadrant H. The other end of the reversing handle F is connected to one end of

the short double lever K, the other end of which is moved by a connecting rod from a stud joint J on the back of the weigh-shaft of the main engines. The slide-valve spindle is attached to the double lever K at an intermediate point I, as shown also in the plan, Fig. 7, Plate 3.

The effect of this arrangement is that when water is admitted into the lower cylinder by a downward movement of the reversing handle raising the slide-valve, as shown in Fig. 5, Plate 3, the hydraulic rams are then moved in an upward direction, carrying with them the weigh-shaft lever D, as shown in Fig. 6, and reversing the engines accordingly; and by the same movement the stud joint J upon the weigh-shaft is lowered, and closes the valve again, so that the two hydraulic rams are then held fast in whatever position they may be placed in. This counteracting cut-off enables the engineer at once to place the reversing links of the main engines at any degree of expansion and hold them there, by simply moving the reversing lever into the desired position in its quadrant, when the rams will follow at once into that position and stop there.

Steam Reversing Gear.—When it is desired to avoid putting down a pumping engine and steam accumulator, a modification of the above hydraulic reversing gear is used, as in Plates 4 and 5. In this apparatus a double-acting steam cylinder A is the moving power, and a similar water cylinder B of one eighth the area is coupled to it for the purpose of controlling its action, and holding the reversing gear locked stationary in any position to which it is shifted, by means of the slide-valve C. The water in this cylinder is not under pressure, but simply holds the piston stationary when the water is prevented from passing from one end of the cylinder to the other by means of the slide-valve C, which closes or opens the communication between the two ends of the water cylinder. This valve is made double, with one slide on each side of the central spindle, as shown to a larger scale in the section, Fig. 15, Plate 5; so that whichever way the pressure of the water in the locking cylinder acts when the

valve is closed, one or other of the two slides is always pressed tight on its face, and effectually prevents any water from passing. This water valve is coupled to the hollow piston-valve D of the steam cylinder, shown in section in Fig. 16; and the two valves are moved together by the reversing lever E, which is centred not upon a fixed point, but upon an intermediate lever F taking its motion from the weigh-shaft lever G of the main engines, as shown also in the plan, Fig. 14. The piston rod is connected to the weigh-shaft lever G by side rods, and the action of the apparatus is similar to that of the hydraulic reversing gear previously described; the engineer opens both the steam and water valves by moving the reversing handle E, as shown in Fig. 12, and the weigh-shaft lever G then follows this motion, as shown in Fig. 13, and by the same movement closes the valves again.

The drawings show this steam reversing gear as fitted to the engines of the steamship "Macgregor," of 370 nominal horse power; and these engines can be reversed in three seconds by means of this apparatus, with a power of only 11 lbs. at the end of the reversing handle, which is $2\frac{1}{2}$ feet long. The reversing links of the engines can be placed at any desired degree of expansion by putting the reversing handle into the corresponding notch of its quadrant, and the hydraulic cylinder then holds them securely in that position.

Hydraulic Steering Gear.—In the Hydraulic Steering Gear the character of the work to be done in moving the rudder from port to starboard and the reverse is much the same as in shifting the links of the main engine from ahead to astern; and therefore the machinery which is effective in the reversing gear suffices also for steering. The only additional provisions in hydraulic steering gear that are not wanted in reversing gear are:—1st, that the power applied to the steering gear should increase in proportion to the angle at which the rudder is moved over; 2nd, that under any excessive strain the machinery should give way, allowing the rudder then to come amidships, but immediately causing it to return when the extra strain is removed; and 3rd, that whilst the hydraulic

steering rams and cylinders are placed aft for direct connection to the rudder, the valve for controlling them should be placed on the bridge and worked there under the eye of the officers of the ship.

In Plates 6 and 7 is shown such an arrangement of hydraulic steering gear, connected to the rudder post A by the main tiller B, which is keyed upon it. The end of the tiller is turned cylindrical to allow the sliding block C to slide radially upon it; and this block is connected by trunnions to the hydraulic rams D D working in the cylinders E E, Fig. 17, from which separate pipes are carried to the admission ports in the slide-valve F that is placed at the bridge. When the main tiller is moved in either direction towards its extreme position, the sliding block runs out upon it, and the proportionate extent of motion or the effective leverage of the rams is increased, until the power over the rudder becomes doubled when the rudder is hard over at 45° on either side of the midships position. This is an exceedingly useful property of the steering gear, because in steering with the rudder amidships on long voyages the quantity of water used is proportionately reduced. A wire cord is carried in each direction from the hydraulic rams to a quadrant G, Fig. 17, so that any motion taking place in the rudder post communicates a similar motion to the quadrant. The object of this quadrant is to effect an automatic cut-off by the slide-valve F; and also to show by means of an indicator on deck the exact position of the rudder at all times.

The steering valve F is shown in section to a larger scale in Fig. 20, Plate 7; it is three-ported, the two end ports J J leading through the pipes to the hydraulic cylinders astern, while the centre port is the exhaust; the water from the accumulator enters the valve-chest by the port H. Relief valves K K are provided in connection with each hydraulic steering cylinder, for the purpose of relieving the rudder from any excessive strain in the event of a heavy sea striking it. These relief valves remain shut, so long as the strain on the rudder and the hydraulic rams is less than that due to the pressure of about 700 lbs. per square inch acting on the area of the rams; but the moment any strain on the rudder exceeds this pressure by about 80 lbs. per inch, the valves open internally,

and allow the water to flow back into the accumulator, driving the accumulator piston up against a steam cushion. In this way through the rams of the steering gear the rudder is practically held in position at all times by an elastic pressure of steam.

The self-closing action of the slide-valve is very similar to that in the hydraulic reversing gear. The steering tiller L, Fig. 18, is fixed upon the shaft N which passes down from the bridge to the valve F on the main deck, terminating in a crank at the bottom. This crank by a pin and connecting link works one end of a lever I, Fig. 17, the other end of which is attached by a similar connecting link to a crank pin in the quadrant G; and to the middle of this lever I is jointed the slide-valve spindle. If the valve is opened by moving the steering tiller L and the lever I, water is at once admitted to one of the steering cylinders and exhausted from the other, causing the rams to move the rudder. But as the quadrant G receives motion from the rams by the wire cord, and therefore moves through precisely the same angles as the rudder, its crank pin is carried in the opposite direction to the crank on the shaft N, and the slide-valve is by that means shut again; and any further movement of the steering tiller L will produce further motion in the rams, with a corresponding counteracting motion of the quadrant. The slide-valve is also opened immediately by the quadrant whenever the rudder is driven amidships by the excessive strain of a heavy sea, and it thus gives a double relief to the water at that moment; but the quadrant closes the valve again on the rudder returning to the position from which it was disturbed. The shaft N of the steering tiller has a tubular casing, which is fixed to the quadrant below and is carried up to the top of the steering pedestal; and a pointer P is keyed upon it, which travels over a graduated arc and indicates the position of the rudder, as shown in the plan, Fig. 19. In this way any angle at which the steering tiller L is placed will be followed by a corresponding angular position of the rudder, and this is shown at once by the small pointer P.

The working of this apparatus is perfectly smooth and noiseless, in consequence principally of the circumstance that not a single

cog wheel is employed. Also the slide-valve required is so small, that with the steering tiller of 3 feet length in the ferryboat "Birkenhead" it is found so little power is required to move it that a boy could easily steer. An exactly similar valve, with pipes only $\frac{7}{8}$ inch diameter, sufficed to steer the steamship "Mikado" of 3000 tons and nearly 400 feet length, putting the rudder over from amidships to hard aport or starboard in 16 seconds.

Hydraulic Hoist.—The hydraulic machinery for discharging cargo is of two kinds; namely hoists which reciprocate only, and those which have a continuous rotary motion. The first is the least expensive, the simplest, and the most efficient and durable; it is shown in Figs. 21 and 22, Plate 8, and consists of a hydraulic cylinder having a ram A, which carries the movable pulleys B on a crosshead, and the cylinder end has a similar arrangement of fixed pulleys C. A chain passes to and fro round the two sets of pulleys in the order of "block and tackle," one end being fixed to the cylinder and the other end passing over a jib into the hold. This hoist is well known as that invented and largely introduced ashore by Sir William Armstrong, with the most perfect success. It will noiselessly raise loads any height at a speed of 5 feet per second, and stops by self-acting arrangement when at the extremity of its range; and it is such a durable arrangement that many examples are to be found in the London docks which have been at work from ten to twenty years without repair except renewal of chains, though constantly discharging goods at this high speed. In the hydraulic hoist as shown in Plate 8 the slide-valve D is moved by the lever E, which has a balance weight at the outer end; and a rope F attached to the lever passes over a pulley and down into the hold of the ship, having at its end another equal balance weight. By this means the hoist can be set in motion from any deck by pulling the rope, thus dispensing with a special attendant for the hoist; and by a tappet on the cut-off rod G it is made self-stopping when at its highest point.

Hydraulic Winch.—The rotary kind of hoist is shown in Plates 9 and 10. Two winding barrels A A with their breaks are

mounted in the frames B B, Fig. 23, the outer ends of their shafts having warping ends C C keyed on. The winch is driven by the rams, $3\frac{1}{2}$ inches diameter, of three oscillating hydraulic cylinders D, which act upon the same crank pin, Fig. 24; and they receive and exhaust their water through the trunnions by means of partially balanced cylindrical slide-valves E, shown in section in Figs. 25 to 27, the casing of which remains stationary, whilst the cylindrical valve or plug E moves with the oscillation of the cylinder. When this hoist is required to discharge light cargo, such as tea, grain, &c., four ropes can be worked out of one hold, the engines constantly running at 30 revolutions per minute; and with barrels and warping ends of 2 feet diameter a discharging speed of 187 feet per minute is obtained.

For the purpose of adapting the power of the winch to suit great differences of load, an arrangement is made for readily changing the throw of the crank whilst at work. The crank pin is fixed in two discs F, which are placed eccentrically to the axis of the winch; and each of these discs revolves within a recessed face-plate fixed upon the winch-shaft, and is connected to it by a sliding bolt I, Fig. 23. A series of corresponding holes for the bolts are provided in the two discs F, for securing them by the bolts in different positions; the two bolts are withdrawn together by a lever, and then pushed in again by spiral springs. For the lightest load the hydraulic engine is set at 6 inches stroke; and when the full 2 ton load is to be raised, the sliding bolts are withdrawn and the eccentric discs allowed to revolve into the position giving the greatest throw of the crank pin, and the bolts are then allowed to drop into the holes. The engine is then at a stroke of 18 inches, and there are three other intermediate positions of 9 to 12 and 15 inches stroke for proportionate loads. In this way the quantity of water used is made to approximate to the work done; and as the stroke can be altered whilst the engine is running, no time is lost.

When raising the heavy loads the engine does not exceed a speed of 20 revolutions per minute, which certainly does not involve any material wear and tear. Gearing is entirely dispensed with in this

hydraulic winch, in consequence of the high pressure of water used, which gives a moving force of 3 tons upon each of the three rams acting on a crank of 9 inches radius ; and this gives sufficient driving power when attached directly to the winding barrel. Also the entire absence of the noise and vibration so usual where gearing and quick-running steam engines are employed is not the least of the advantages in the hydraulic winch.

Hydraulic Swinging Gear for Jibs.—In connection with either of these hoists the arrangement shown in Fig. 28, Plate 11, is used for swinging the jibs that are suspended from the mast for putting cargo over the side of a vessel. A pair of small hydraulic cylinders and rams A are attached one on each side of the mast B on deck, each ram carrying a pulley C, round which a chain is passed, and its end fastened to the cylinder with provision for tightening at D. This chain passes round and is fixed to a pulley E upon the base of the swinging jib F, and serves to move the jib round by the action of either cylinder alternately. The slide-valve G admits water to either cylinder, and is moved by a lever H, which is centred at the bottom of the joint-pin of the jib. The valve is thus opened by the attendant moving the lever to any position in its quadrant, while the actual swinging of the jib shuts it again, in the same manner as in the valve gear of the reversing or the steering apparatus. By having adjustable stops in the quadrant, the jib can always be swung by power exactly plumb over the centre of the hold of any craft alongside.

In all the above plans of hydraulic machinery, the pumping engines, steam accumulator, and tank are all placed in the engine room. The tank is charged with water mixed with methylated spirit to the strength sufficient for resisting frost; or other fluids are employed, of which there are several suitable for the purpose. The fluid is led along a pressure main from the winch furthest aft to the hydraulic engine on the capstan, with branches and stop-valves connecting the different hydraulic machines ; and it is returned again by an exhaust main into the tank, which is closed water-tight to prevent evaporation, one charge of fluid being thus

worked continuously. The pressure mains are of wrought iron, put together with right-and-left-handed screwed coupling boxes; one pipe is coned and the other faced flat at the end, so that the joint is drawn together metal and metal without any packing, as shown half full size in the section, Fig. 29, Plate 11.

The hydraulic reversing gear is attached to the main engine frame, with the reversing handle at a convenient height from the starting platform. The hydraulic steering cylinders are placed aft, and connected by wrought-iron pipes with the slide-valve; and the steering tiller is placed amidships, or on the bridge. The hydraulic winches are usually placed on the main deck; and in the reciprocating hoist, the hydraulic rams work through the spar deck.

The advantages of this system of hydraulic machinery on board ship may be stated as follows:—

1st. The motive power is placed in the main engine room, is automatically started and stopped, and is kept under the care of a skilled attendant.

2nd. No steam pipes are carried beyond the main engine room; thus avoiding the heating of decks, and leaking joints from steam pipes carried along the ship, and blowing-through of condensed water from steam winches on deck.

3rd. A comparatively great speed is obtained in the performance of the various work in discharging cargo, steering, reversing, &c.; and this speed is obtained without any gearing, and without the attendant noise and vibration, and consequently with little wear and tear of machinery.

Mr. D. Halpin enquired, in reference to the arrangement of hydraulic steering gear described in the paper, how an increase of power was obtained in moving the rudder over to either side from its centre position.

Mr. Brown replied that, as the connection of the rams to the main tiller was made by means of a block sliding longitudinally upon the tiller, the relative motion of the rams, which was equal to that of the tiller when the rudder was in its centre position, increased gradually in moving the rudder over to either side, until in the extreme positions of the rudder at 45° on either side of the centre the motion of the rams became double that of the tiller; and consequently the power of the rams over the rudder at either end of its range was double of their power over it when in midships.

In reference to the drawing shown of the steam accumulator, he wished to remark that this was intended to illustrate the general arrangement employed; and the exact size would be determined by the actual requirements of the hydraulic machinery to be worked by the accumulator in any particular instance.

Mr. B. Walker thought that hydraulic power on board ships would be very useful, and that the hydraulic steering gear described in the paper would answer its purpose well, and would be found very handy and advantageous; it certainly was a highly important step accomplished that by this means the steering of a large ship could be performed by only a boy's power. A hydraulic winch however, such as that shown in the drawings, he considered would take much more coal to work it than if it were driven direct by steam power. Some years ago he had had an opportunity of practically testing this question by taking the gearing off an ordinary foundry crane, and applying the same belt which had driven the gearing to drive a pair of pumps for charging an accumulator to work the crane by hydraulic pressure; the result was that, in raising a load at the same speed and through the same distance, and with the same speed of the driving belt, the hydraulic power would not lift more than half the weight which had previously been lifted by the gearing. He considered therefore that if three steam cylinders were employed, in place of the three rams of the hydraulic winch now described, the result would be obtained with half the consumption of coal, and with the same advantage of dispensing with gearing. For discharging cargo

from ships, Sir William Armstrong's hydraulic hoist shown in the drawing appeared to him far preferable to the hydraulic winch; and although he had found all hydraulic apparatus entailed double the consumption of coal as compared with steam power, yet the rapidity of hoisting that was obtained by the hydraulic ram and multiplying chain pulleys was so great, and the facility of working so important, that he considered the loss of fuel was in many cases more than compensated by these advantages. In a foundry too there was a great advantage in the use of hydraulic power in the moulding shops, on account of its doing away with the disturbing noise and vibration of gearing, which interfered seriously with the work of the moulders. He concurred with the remarks made in the paper about the rattling of the gearing in ordinary steam winches, and the liability of the steam pipes to leak; but it must be remembered that a great deal of the rattling arose from the machines not being well constructed, and that, while it was true the steam pipes were apt to leak, hydraulic pipes would leak too if the joints were not well made.

Mr. Brown said in comparing the steam and hydraulic winches the former must be taken in the condition in which they actually existed upon shipboard, and not as they ought to be. An ordinary steam winch, with link motion indifferently fitted, with its valves and pistons leaking, placed in the hands of a common seaman, would not work nearly so economically as the hydraulic winch. Moreover when steam was applied direct to a winch, it would run off whenever the load was suddenly removed, but this was not the case with a hydraulic machine; when lifting a load of 2 tons with the hydraulic winch he had suddenly disengaged the clutch, but the winch did not run off. As to the joints of steam pipes being easily made tight and those of hydraulic pipes not being easily made tight, his own experience was decidedly in favour of hydraulic pipes; every time the steam pressure rose and fell the steam pipes were more or less in motion, and however tight the joints were made in the first instance they were sure sooner or later to begin leaking. Steam pipes were indeed a decided nuisance in almost any situation, but particularly on board ship, where they had

frequently been taken out from below the decks, and placed upon the decks in boxes, so as to allow of more readily getting at the joints, because they could not be kept tight. In hydraulic pipes on the contrary a joint once made tight remained tight; indeed it rusted up and could not be undone again without difficulty. The consumption of coal with the hydraulic winch he had not tested by a dynamometer, because in this application of power the question of economy of fuel was not considered by shipowners as of any importance whatever in comparison with the great advantage of getting rid of leakage and consequent risk of damage to the cargo. From the bad state of repair in which steam winches were generally kept, with no one to look after them, he could safely say they were anything but economical machines. The revolving engine with three rams had been successfully introduced by Sir William Armstrong for working capstans on shore; and in the hydraulic winch described in the paper the same practice had simply been adopted with a view to its introduction on board ships.

Mr. R. H. Tweddell observed that an instance of the relative economy of steam and hydraulic power was afforded by the application of each to riveting, which he thought was a parallel case to that of the winch. With a hydraulic riveter he had used only a small boiler heated by the waste heat from the rivet-heating furnace, which raised steam considerably more than sufficient to work the pumps for charging the accumulator; and he was sure no steam-riveting machine with the same quantity of steam could have done the same quantity of work. This he considered sufficient proof that there was no loss but a decided economy in transmitting power by water pressure; for the question was merely one of the transmission of power, whether gearing were used, or steam pipes, or an accumulator. The plan of loading the accumulator by steam pressure on a piston seemed to him not so good for general application as the use of a dead weight, although he knew the difficulties attending the employment of the latter on board ship, on account of the heavy weight required to be carried for the purpose. In the steam accumulator the water pressure might be liable to fall 200 or 300 lbs. per square inch below the proper amount, owing to

fluctuations in the boiler pressure, which would be a serious objection for work requiring a constant definite pressure; means might however be provided for regulating the pressure, and where there was an ample surplus of pressure the fluctuations would not matter. The application of hydraulic power to a winch, by means of three oscillating cylinders, appeared to him capable of improvement; and he thought the three-cylinder engine of Brotherhood with trunks and internal connecting-rods was a superior arrangement. As regarded the relative advantage however of the hydraulic winch and the hydraulic hoist shown in the drawings, it must be borne in mind that in the latter there was a greater loss of power, owing to the friction being multiplied very largely by the chain passing so many times round the pulleys. The advantages of using hydraulic power to perform work on board ship he considered were just as great as in its application for large works on land, where it would be attended with a very important economy of fuel, as he had endeavoured to show in the paper he had read upon that subject at a previous meeting (see Proceedings Inst. M. E. 1872 page 188).

Mr. F. W. Webb said he had suggested the use of Brotherhood's three-cylinder hydraulic engine as a capstan engine, and he believed the first so applied had been put up by himself. He had had one of them working five months night and day at the Broad Street railway station in London, and it appeared now as good as when first put to work; he quite agreed that it was a great improvement over other hydraulic engines having stuffing-boxes. There was only a single circular disc-valve for the three cylinders of the engine; and there were no stuffing-boxes either for the cylinders or for the valve-chest, and no packing except the leathers of the trunks, which had lasted already without renewal during five months' constant work night and day, and were still in good condition. The machine described in the paper he thought would be quite as liable to leak as a steam winch, if attended to only by a sailor, as on shipboard.

Mr. H. Davey observed that hemp packing was used for the piston of the steam accumulator described in the paper, in connection

with the self-acting mode of keeping the packing steam-tight by the pressure of the steam itself; and he enquired what was the reason for adopting hemp packing in that instance, and whether the slow speed and intermittent action of the piston rendered the hemp packing more advantageous than metallic packing; in other cases he believed hemp-packed pistons had been generally superseded by the use of metallic packing. The several applications of hydraulic power shown in the drawings appeared to him to be thoroughly satisfactory, with the exception only of the hydraulic winch. The application of water pressure to all purposes connected with the loading and discharging of the cargo of ships was a very advantageous one, though there seemed to be little new in the construction of the lifting or swinging gear in the drawing shown of Sir William Armstrong's well-known hoist as arranged for use on board ship. With reference to the hydraulic winch, he agreed in the opinion that a winch of that construction would use a great deal more steam to do a certain amount of work than an ordinary steam winch working expansively; for the hydraulic winch was worked by a constant pressure of water supplied from the accumulator, and there was no expansive working; and the only provision for varying the consumption of water to suit the weight of the load was by changing the throw of the crank in the manner described in the paper. This however could not he supposed be done while the winch was working, and it would have to be brought to rest for the purpose, which would take so much time that in discharging cargo the man working the winch would not stop it to make the change, but would work it constantly with the same throw of the crank and consequently with a uniform consumption of water, irrespective of the varying loads lifted. He had constructed hydraulic capstans with three radial cylinders, in which the cylinders were in three different horizontal planes, working upon a single crank instead of upon a three-throw crank, and the crank shaft was placed vertically instead of horizontally. But he had found that, in order to prevent leakage under the high pressure of water employed, the rams had to be packed very tight, and their power was so small and their speed so high that the friction was very much greater than in the direct-

acting hydraulic hoist, he believed as much as three or four times greater for the same amount of work done. Instead of the three rams acting upon three cranks at equal angles of 120°, which had been adopted by Sir William Armstrong for the first hydraulic capstans, experience had now led, he believed, to the almost universal substitution of a pair of double-acting cylinders working cranks at right angles, and fitted with combined pistons and rams, the rams being half the area of the pistons, and the accumulator pressure being maintained constantly upon the annular area in front of the pistons, so as to equalise the power in each stroke. This plan, which had now been adopted at most of the recent dock works, had been found far preferable, he understood, giving a better and steadier motion than had been obtained in the original plan with the three single-acting rams placed at equal angles.

The use of circular disc-valves, for admitting the water pressure through the trunnions of oscillating hydraulic cylinders, or for any other application where they would have to work under a considerable pressure, would he thought be attended with much difficulty; that kind of valve had been tried frequently for steam engines, especially for oscillating cylinders, but had not been found to answer under high pressures, on account of the outer part of the valve face wearing faster than the centre portion, so that the valve began to leak; and this objection would be still more serious under the much higher pressures used with hydraulic power. For hydraulic capstan engines an ordinary rectilinear slide-valve was used by Sir William Armstrong, but great difficulty was experienced even with this, in consequence of the rapid wear under the high pressures employed. The valves indeed he considered were at present the most troublesome part of hydraulic machines working under high pressures; and though he had tried various means of relieving the pressure on the back of the valve, he had not found any plan successful for that purpose. For moderate pressures he had found the most durable material for the valves was lignum vitæ working on brass faces; and he should be glad to hear the result of Mr. Brown's experience in the working of valves under high pressures of water. Reference had been made to hydraulic riveting

with a view to show the relative economy of using hydraulic power instead of steam; but he did not think that riveting afforded at all a parallel case, because with a steam riveter there was no expansive action of the steam, and in that exceptional instance therefore a good deal more steam was used than would really be necessary for performing an equivalent amount of mechanical work of a different description.

Mr. Brown said, in reference to the plan of loading the accumulator by steam pressure, he had found this to be decidedly more economical than a dead-weight accumulator; and condensation of the steam might be entirely got rid of by well clothing the steam cylinder. The steam accumulator was free from the danger attending the sudden stoppage of a heavy descending weight, and consequently did not require the delicate safety valves which were necessary for providing against that danger; and another important advantage was that the engines started to work much more easily, having no heavy weight to put into motion, and for the same reason they could also be worked more expansively and therefore with greater economy.

For the packing of the steam piston in the accumulator he had made many trials of metallic packing, but had not succeeded in getting it to answer, and had therefore been led to revert to hemp. Metallic packing would do well enough for quick-moving pistons, such as those of locomotive engines, because it was evident that the higher the speed of the piston the less need there was of any packing at all. But the steam piston of the accumulator was always on the move with a very slow motion and constantly under the full pressure of the steam; it was necessary therefore that it should be made absolutely steam-tight, and hemp packing had been found the best for this purpose. He had adopted Tuck's packing, consisting simply of a roll of canvas carefully made up so as to be of uniform substance throughout its length. This packing lasted from twelve to fourteen months and remained perfectly steam-tight without requiring any attention; in about that time it became worn out, and had to be renewed.

He was still making trials of metallic packing, but was afraid it would not succeed; and he should be very glad of any information as to the pressure of steam under which a metallic-packed piston would remain perfectly steam-tight without any leakage. He did not think any new steam engine with metallic packing was ever steam-tight until it had run long enough for the cylinder to become glazed; this was the case with the cylinder of the steam accumulator after about a year's work with the hemp packing, and there might be a better chance then of working with metallic packing, though he had not yet succeeded in accomplishing this. It was indeed most desirable to be able to use metallic packing for the steam accumulator, and this was almost the only thing required to render it satisfactory in every respect.

For the packing of the stuffing-boxes of the rams and slide-valves of hydraulic machines he had found hemp to be the best material, and far superior to leathers, which he considered were most objectionable for hydraulic purposes, and should always be avoided if possible. Hemp was practically indestructible in water, and with a sufficient quantity of hemp packing a stuffing-box could be made perfectly water-tight under the highest pressures. This was the experience with Sir William Armstrong's hydraulic hoists and accumulators; and in the steam accumulators the water stuffing-boxes of the rams had continued constantly in use without the hemp packing being touched for three years. That was longer than he had found any leathers stand under similar circumstances.

The Chairman enquired whether it was common hemp that was used for the stuffing-boxes, and in what way it was applied.

Mr. Brown said it was common hemp, merely plaited very tight, and it seemed to be quite indestructible for hydraulic purposes. It formed so good a packing, that even when all the bolts in the gland of a stuffing-box were slacked back, the packing remained water-tight under the highest pressures, without any leakage whatever. Having originally used leathers, he had been led by experience to adopt hemp packing instead, because he had found that when a leather gave way it was necessary to take the machine to pieces, in order to get a new one on round the ram or valve-spindle,

as there was no means of putting it on in separate rings; but hemp packing was applied round a ram or spindle in segmental rings with the greatest ease.

With regard to the wear of the valves used in the hydraulic winch, it must be remembered that these were cylindrical balanced valves, and not unbalanced disc-valves; also they were made of specially hard metal, nearly as hard as steel, and were found to work with very little wear.

The CHAIRMAN enquired whether it was gunmetal that the valves were made of; and whether phosphor bronze had been tried for the purpose.

Mr. BROWN replied that the valves were made of a specially hard gunmetal; and he had found no difficulty with these valves when working under a pressure of as much as 700 lbs. per square inch. He was however making some experiments now with phosphor bronze, with a view of finding something still better for higher pressures. The whole subject of the application of hydraulic power to the purposes referred to in the paper was as yet in its infancy, and no doubt the present plans would be greatly improved in the course of time; the steps already taken he believed had thus far been in the right direction. In the arrangement of the hydraulic swinging jib it was true that the only new feature was the addition of the adjustable self-acting cut-off valve to the swinging motion; but the important practical advantage thus gained was that the whole could now be worked by a common seaman or labourer, instead of requiring a superior attendant at higher wages. The object was to render the machines so far automatic that a man of low skill could work them; if this could be done, a great obstacle to the adoption of hydraulic power generally, and particularly in the case of machines working at high speed on board ship, would be got rid of.

In reference to changing the throw of the crank pin in the hydraulic winch by the arrangement described in the paper, there was really no difficulty in accomplishing this at any time during the working of the winch; it was only necessary to withdraw the locking bolts by the lever provided for the purpose, and allow the eccentric

discs to revolve to the required extent, and then let go the lever again, when the bolts would engage in a fresh hole. Of course if the man working the winch were unable to manage so simple a matter as this, he would be equally incapable of working a common steam winch expansively by means of the link motion provided for the purpose; and in either case the economy arising from proportioning the expenditure of power to the work done would alike be lost. In many cases of discharging cargo however, as in the instance of discharging grain, the winch would have to be worked the whole day long without requiring any alteration in the power applied, as the load continued constant; the foreman could then adjust the winch to the proper power on commencing work in the morning, and it was seldom that there was such a miscellaneous cargo as really to require frequent changes in the degree of expansion of a steam winch or in the throw of the hydraulic winch.

Mr. R. H. Tweddell observed, with regard to the use of leather packings for hydraulic machinery, he had himself had great trouble at first in using leathers for packing, and there was no doubt hydraulic power had been brought into disrepute more by the failure of the packing leathers than by anything else. With hemp packings however, when proper care was taken in shaping and fitting them, he had now got them working successfully under hydraulic pressures of from 1500 to 2000 lbs. per square inch; and stuffing-boxes packed with them kept tight even when the bolts of the gland were slacked back, as had been mentioned to be the case. With respect to the use of phosphor bronze for circular disc-valves, he had seen the hydraulic capstan employed by Mr. Webb, which was fitted with a circular disc-valve of that material; and after five months' constant work, even though the valve might be rather more worn at the outside than in the centre, it nevertheless still continued perfectly water-tight.

The Chairman enquired what was the composition of the phosphor bronze employed in that case.

Mr. F. W. Webb replied that it appeared to be simply ordinary hard gunmetal with the addition of a small quantity of phosphorus; and by analysis of some bushes made of this material he had

found the proportion of phosphorus was only from 0·17 to 0·65 per cent.

Mr. J. Ramsbottom enquired in reference to the steam reversing gear, what provision was made for the surplus water which in the upstroke was passed from the top to the bottom of the water cylinder, but for which there was not room below the water piston, owing to the piston rod taking up part of the space.

Mr. Brown replied that a small copper ball open to the atmosphere was provided as a reservoir of water, having a communication constantly open to the central space between the two halves of the double slide-valve in the valve-chest of the water cylinder; the ball was consequently cut off from the cylinder when under pressure, by the closing of the valve.

The Chairman observed that the very interesting paper which had been read showed the skill and perseverance with which the subject had been taken up and worked out, and the important advance which had already been made in adapting hydraulic power to a variety of most useful purposes.

He moved a vote of thanks to Mr. Brown, which was passed, for his paper, and for the valuable results of practical experience which he had given.

The Meeting then terminated. In the evening a number of the members dined together in celebration of the Twenty-seventh Anniversary of the Institution.

Fig. 1. *Plan of Water-Power Transmission Works at Schaffhausen.*

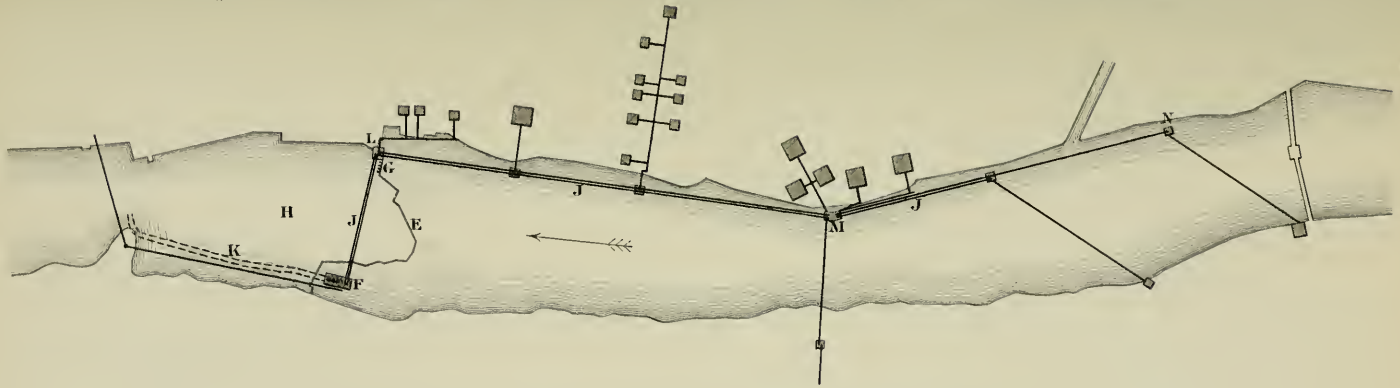
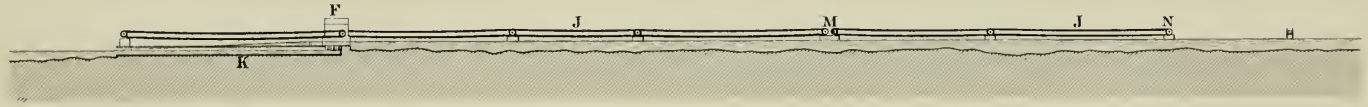


Fig. 2. *Longitudinal Section along River.*



(Proceedings Inst. M. E. 1874.) *Scale* 1/6000th 0 500 1000 1500 Feet.

Plate 12.

POWER TRANSMISSION BY ROPES.

Driving Ropes crossing the River at Schaffhausen.

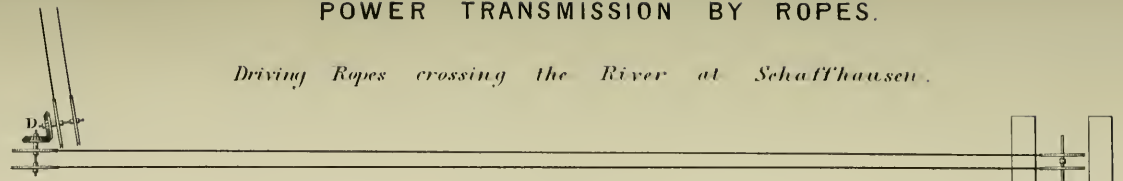


Fig. 3. *Plan.*

Turbine House.

Fig. 4. *Transverse Section.*

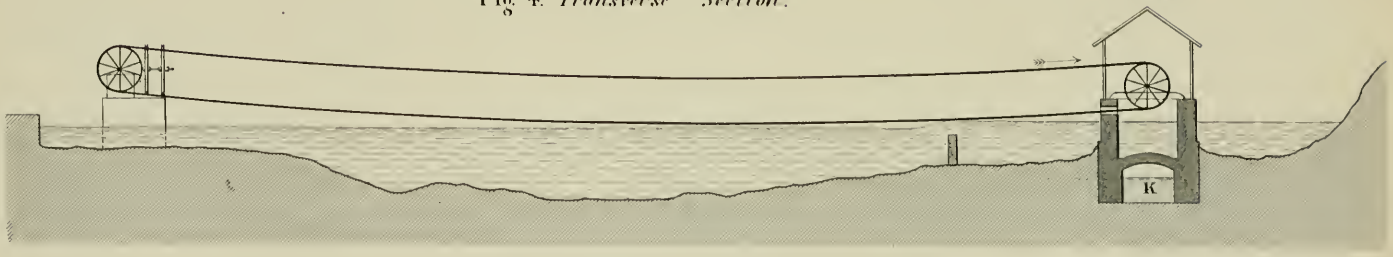
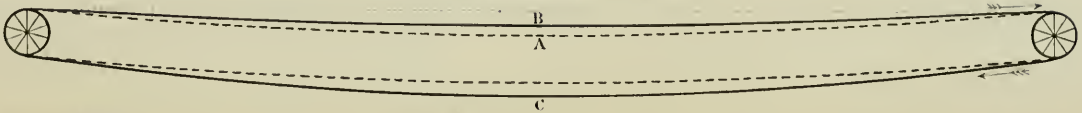


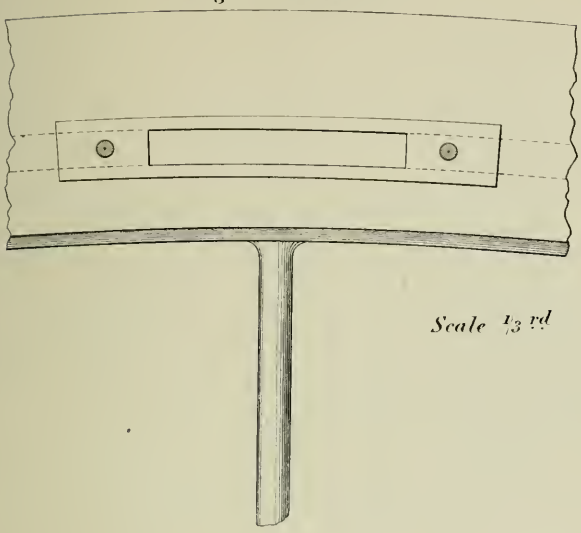
Fig. 5. *Deflection of Rope.*



(Proceedings Inst. M.E. 1874) *Scale $\frac{1}{800}$th* 0 50 100 150 200 Feet.

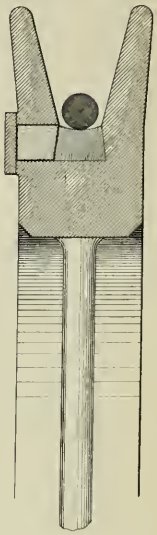
Driving Pulleys at Schaffhausen.

Fig. 6. *Elevation.*



Scale 1/3 rd

Fig. 7. *Section.*



Carrying Pulleys at Loyelbach.

Fig. 8.

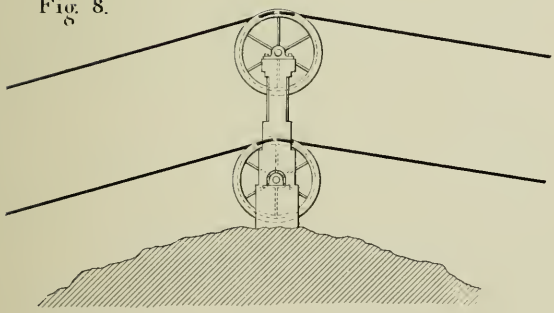
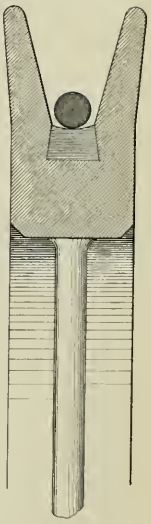


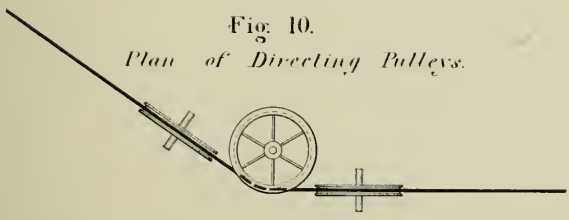
Fig. 9. *Section.*



Scale 1/3 rd

Fig. 10.

Plan of Directing Pulleys.



(Proceedings Inst. M. E. 1874)

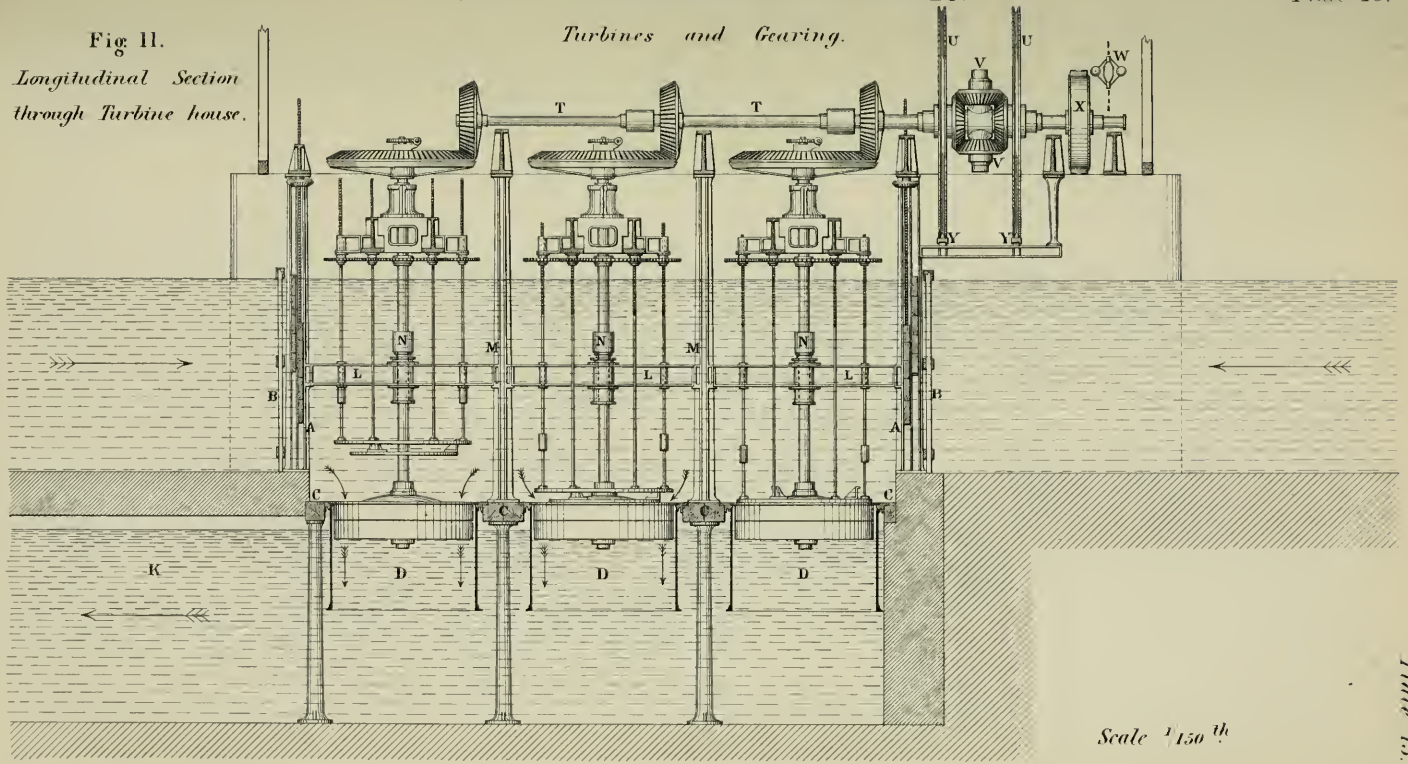
POWER TRANSMISSION BY ROPES.

Plate 15.

Turbines and Gearing.

Fig 11.

Longitudinal Section through Turbine house.



Scale 1/150 th

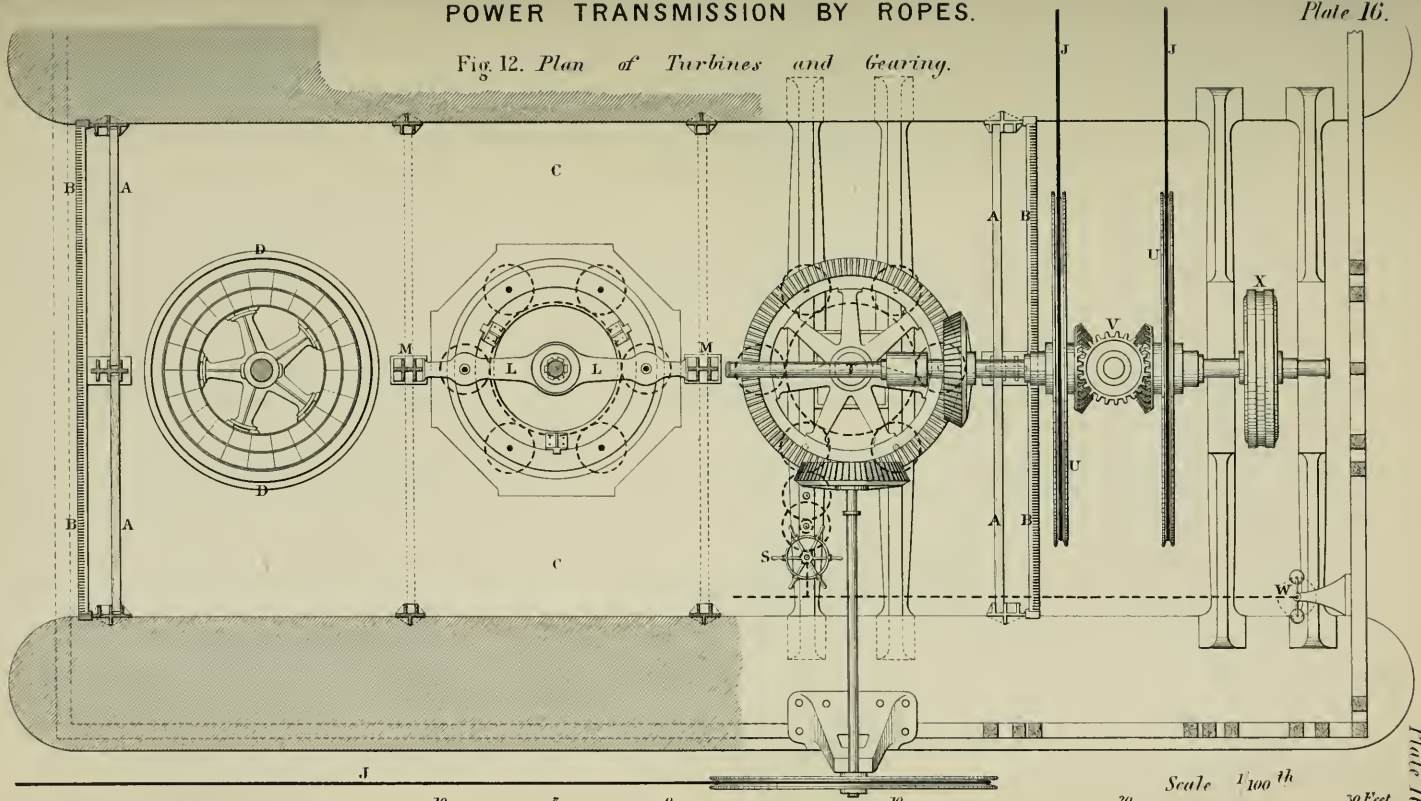
10 5 0 10 20 30 40 50 Feet.

(Proceedings Inst. M.E. 1874.)

Plate 15.

POWER TRANSMISSION BY ROPES.

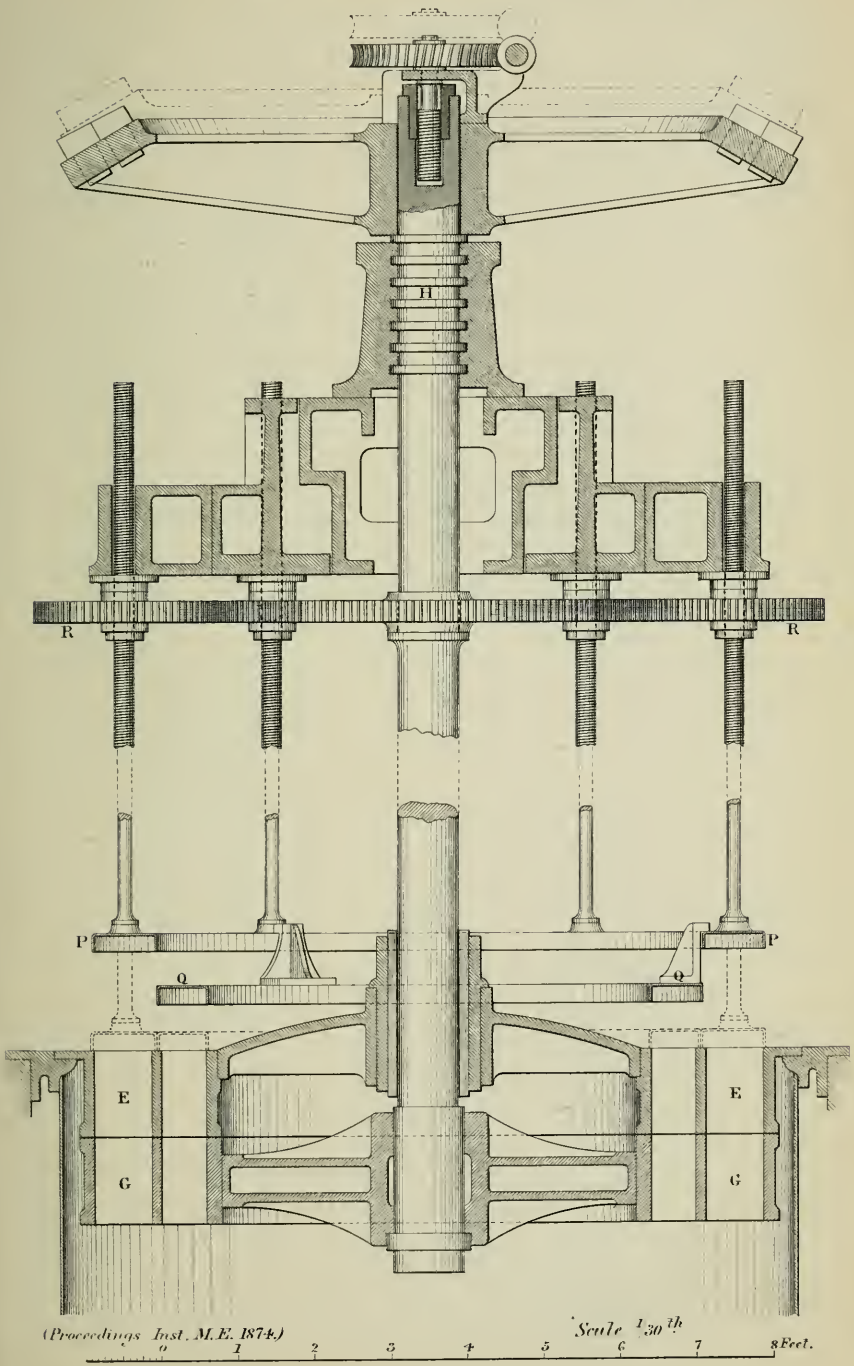
Fig. 12. *Plan of Turbines and Gearing.*



(*Proceedings Inst. M. E. 1874.*)

Plate 16.

Fig 13. *Vertical Section of Turbine and Gearing.*

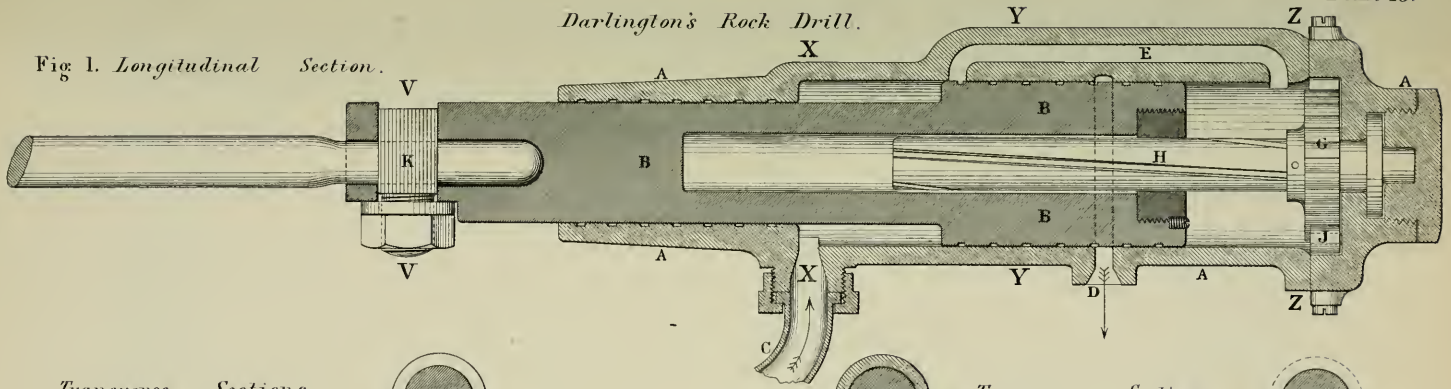


ROCK DRILLING MACHINERY.

Darlington's Rock Drill.

Plate 18.

Fig. 1. *Longitudinal Section.*



Transverse Sections.

Fig. 2. *At* VV.

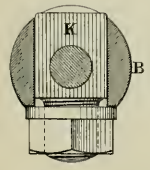


Fig. 3. *At* XX.

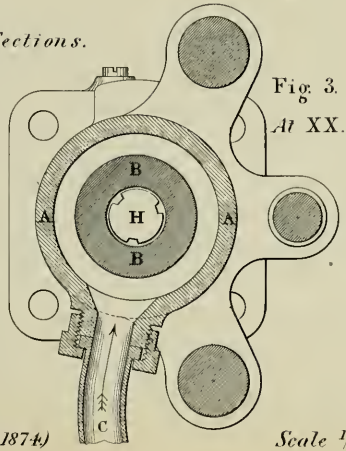
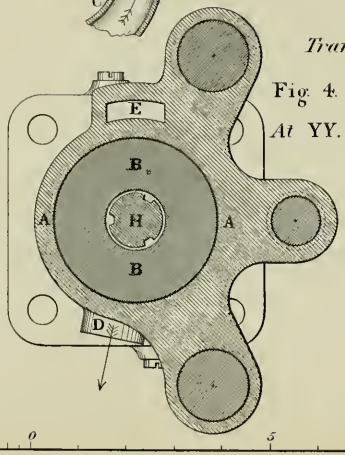
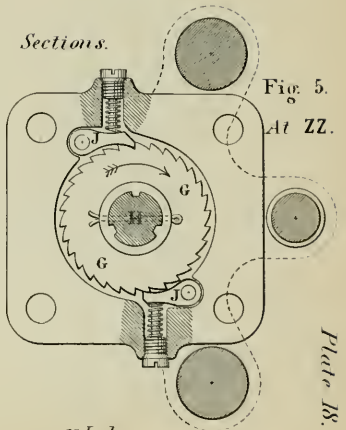


Fig. 4. *At* YY.



Transverse Sections.

Fig. 5. *At* ZZ.



(Proceedings Inst. M. E. 1874)

Scale 1/4 th

0 5 10 Inches.

Plate 18.

Fig. 6. *Rock Drill and Portable Stand.*

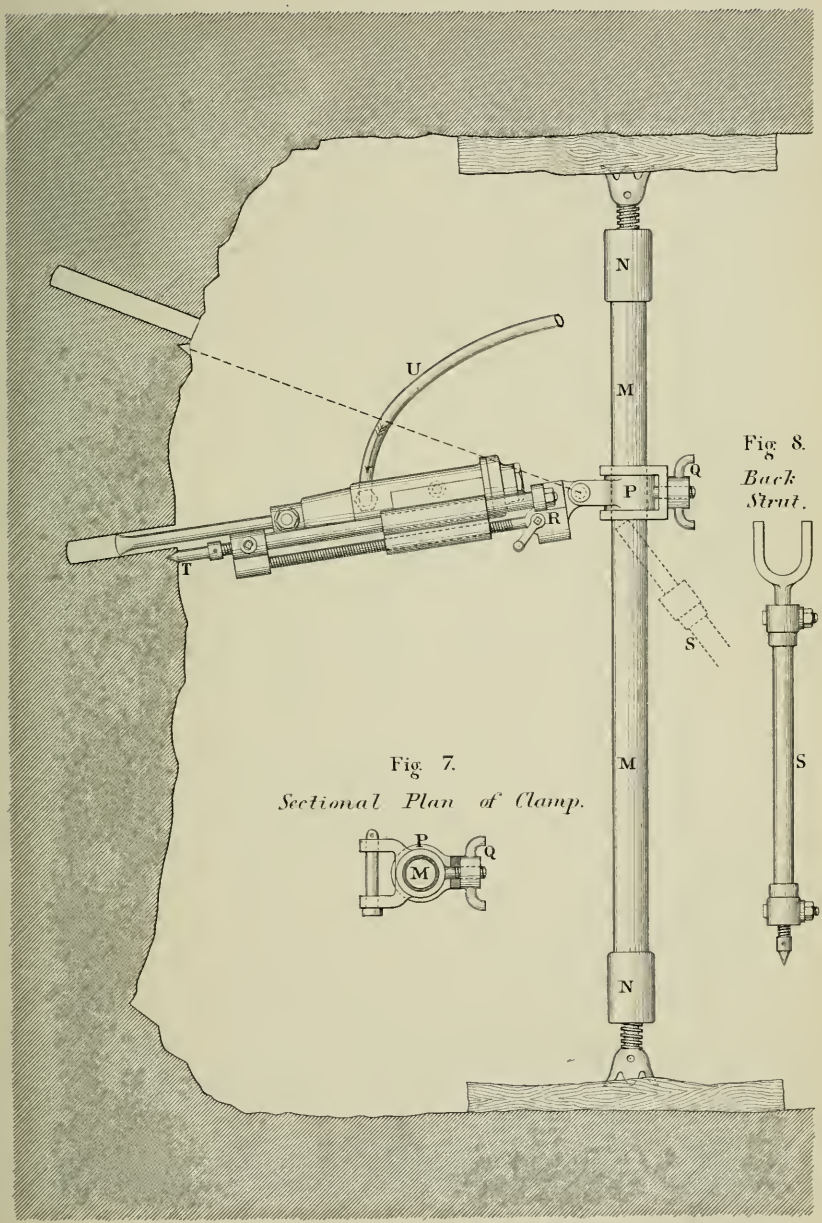
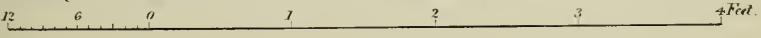


Fig. 8.
Back Strut.

Fig. 7.
Sectional Plan of Clamp.

(Proceedings Inst. M.E. 1874.)

Scale $^1/_{16}$ *th*



Rock Drill on Heavy Stand, for sinking large shafts.

Fig. 9. *Front Elevation.*

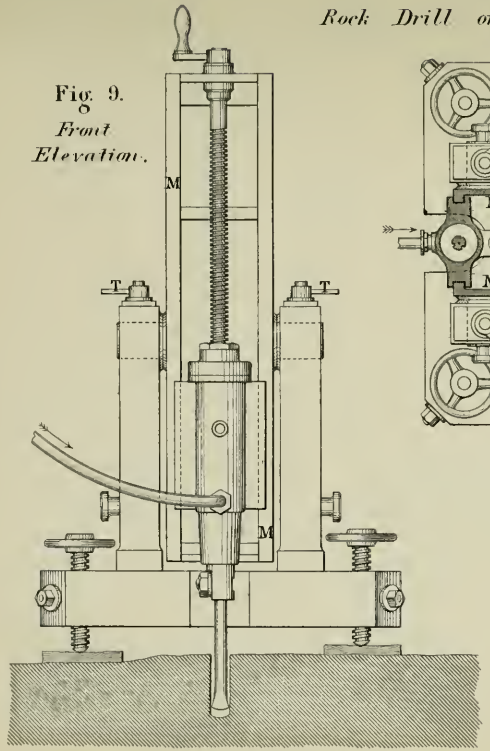


Fig. 10. *Plan.*

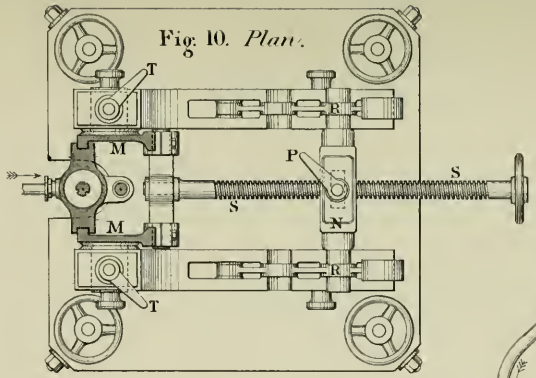
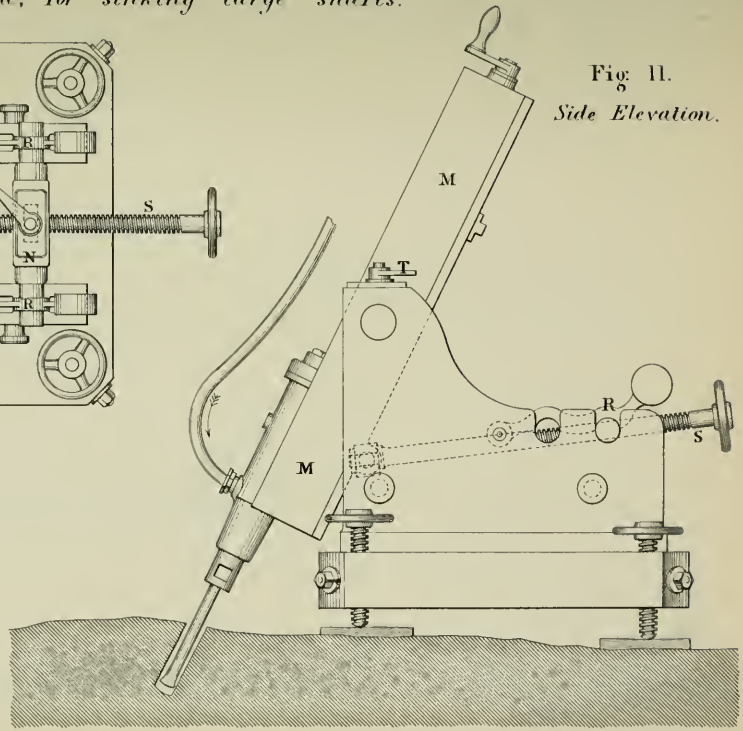


Fig. 11. *Side Elevation.*



(Proceedings Inst. M. E. 1874.)

Scale 1/16th

Ins. 12 6 0 1 2 3 4 Feet.

Plate 20.

ROCK DRILLING MACHINERY.

Plate 21.

Jordan's Air Compressor.

Fig. 12. *End Elevation.*

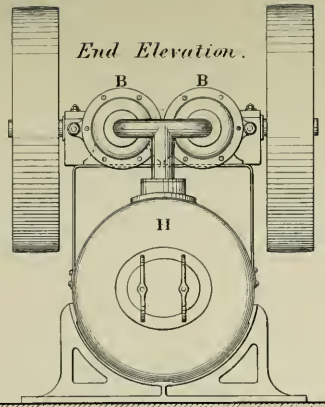
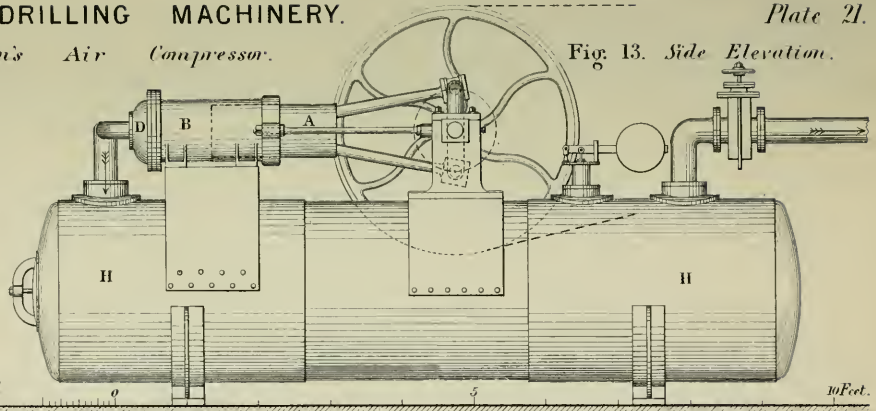


Fig. 13. *Side Elevation.*



Sections of Air-Compressing Cylinder. Scale 1/8th

Fig. 14.

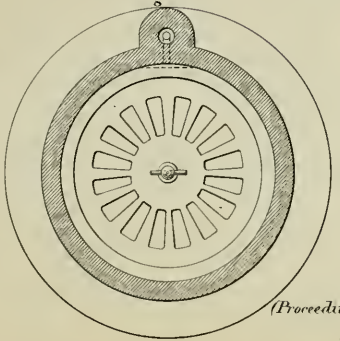


Fig. 15.

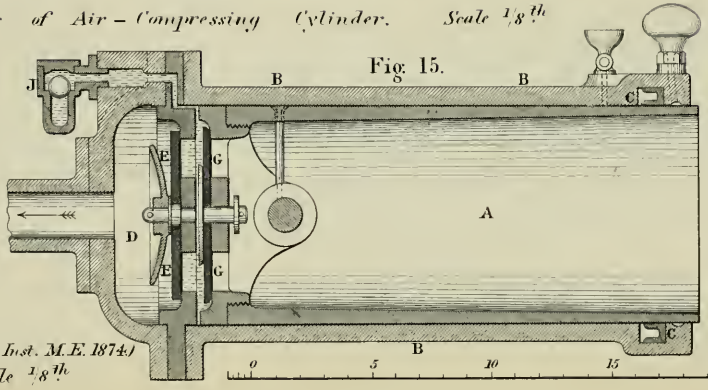
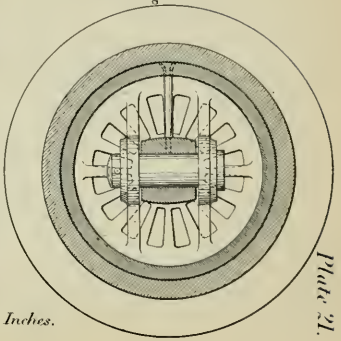


Fig. 16.



(Proceedings Inst. M.E. 1874.)
Scale 1/8th

Plate 21.

Sachs Rock Drill.

Fig. 17. *Longitudinal Section.*

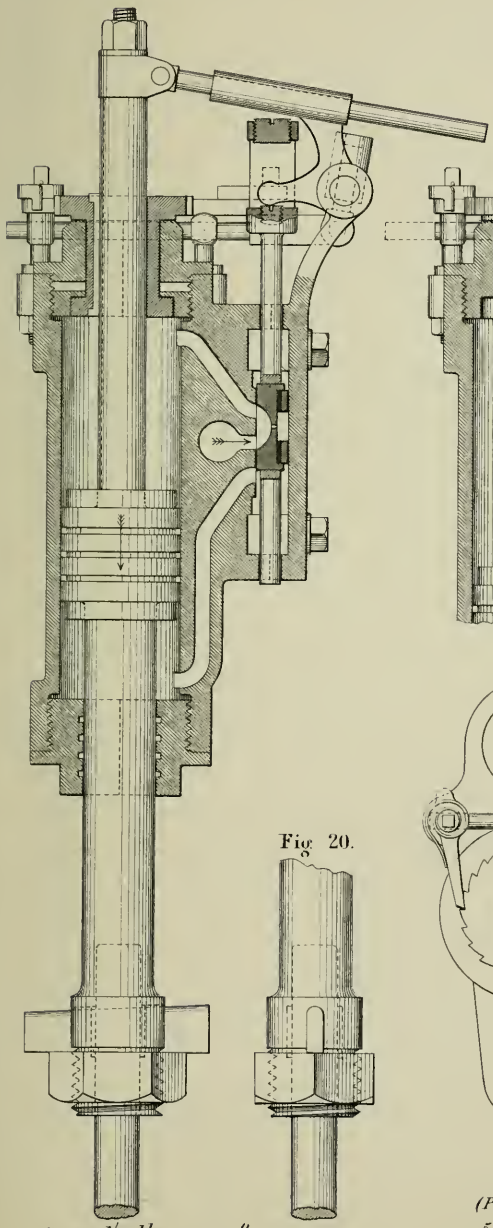


Fig. 18.

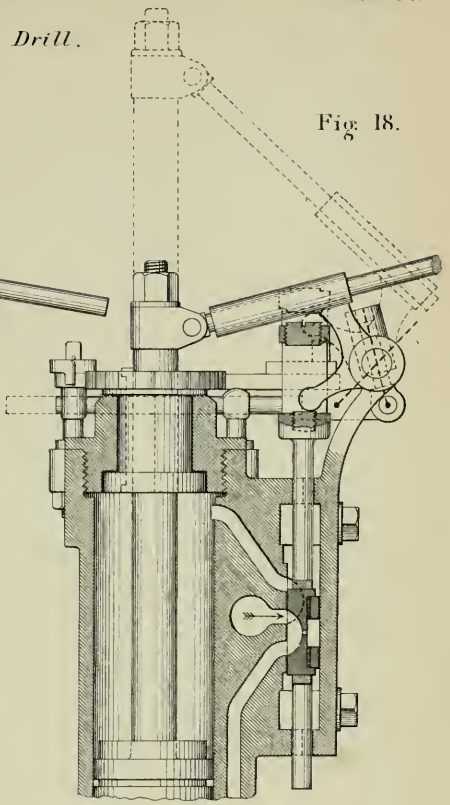


Fig. 19.
End View.

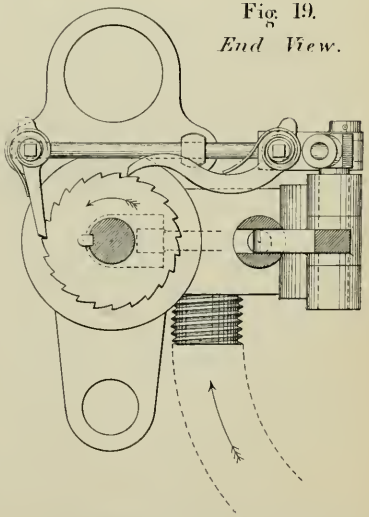


Fig. 20.

Scale 1/4 th

0 5 10 Inches.

(Proceedings Inst. M. E. 1874.)

PROCEEDINGS.

30 April, 1874.

The General Meeting of the Members was held at the Institution of Civil Engineers, London, on Thursday, 30th April, 1874; Frederick J. Bramwell, Esq., F.R.S., President, in the Chair.

The Minutes of the last Meeting were read and confirmed.

The President announced that the Ballot Lists had been opened, and the following New Members were found to be duly elected:—

MEMBERS.

George Barclay Bruce,	London.
William Conyers,	Otago, New Zealand.
Alfred Davis,	Leeds.
William Henry Greenwood,	Manchester.
Nathaniel Grew,	London.
Thomas Bernard Hall,	Birmingham.
John Hopkinson, Jun., D. Sc.,	Birmingham.
Thorvald Klein,	Birmingham.
William Logan,	Durham.
Frank McClean,	London.
Thomas Dyne Steel,	Newport, Mon.
Henry Watkins White,	Gibraltar.
James Young,	Fence Houses.

GRADUATE.

Tomyns Reginald Browne,	Derby.

The following paper was then read:—

ON THE TRANSMISSION OF WATER POWER BY TURBINES AND WIRE ROPES.

By Mr. HENRY M. MORRISON, of Manchester.

There are numerous cases in this and other countries where the adoption of the system of Transmitting Power by means of Wire Ropes would be the means of opening and expanding branches of industry which cannot at present be carried on with commercial success, owing to the want of economical driving power; and it has been left for foreign nations to introduce and carry out this system on a scale of magnitude entirely unknown in this country. Many valuable sites for water power are lying idle for want of building room in their immediate vicinity; and as the cost of conveying the water in canals to the point required would be too great, the power remains unutilised. In the metalliferous districts of this country it is often the case that an enormous mass of material (such as long lengths of wooden and iron rods, shafting, pillow blocks, couplings, &c.) is used in developing a very small amount of work at a great sacrifice of power and money; when the same work might be done at a tenth of the present cost by the use of light Wire Ropes running at high velocities, with a small Turbine or breast-wheel as the prime mover.

It is evident that a result of great industrial and commercial value has been attained, when driving power can without any very sensible loss be transmitted to hundreds and thousands of yards distance; and when after such transmission it is made available for setting in motion the heaviest machinery; whilst in point of economy it costs only one fifteenth of an equivalent amount of belting and one twentieth of shafting. To this mode of transmitting power has been given the name of "telodynamic transmission," and it consists in the use of a pulley of large diameter, set in very rapid

motion, which by means of a light wire rope of small size drives another pulley of equal diameter placed at a distant point; and thus the power is continued forwards to as many points as may be required. This plan was first introduced and practically applied by Messrs. Hirn Brothers of Colmar, Alsace, to whom the writer is principally indebted for his information on the subject.

The first experiment was made in 1850 by Mr. C. F. Hirn at the printed-calico factories of Messrs. Haussmann at Loyelbach near Colmar, Alsace. The works consisted of a number of large buildings separated at some distance from one another, which were required to be changed into a weaving factory. As there was but one steam engine on the works, the expense of transmitting power to the various buildings by ordinary shafting (the shortest length of which would have been 84 yards), or of erecting separate engines, would necessarily have been great; and the desire to obviate this expense resulted in the adoption of the telodynamic system.

The first plan adopted was the use of a band of steel, 172 yards long, 1-23rd inch thick, and 2 inches broad. This was slung as an endless band over two wooden rollers or pulleys 6 ft. 6 ins. diameter, which were placed 84 yards apart, and made 120 revolutions per minute, giving a speed of 28 miles an hour in the band. In practice this plan was found to be open to two objections: the lightest wind agitated the band, and the pulley guides tore it at the points of riveting, whilst the guides themselves were rapidly worn out. Notwithstanding these objections, this plan rendered valuable service, and continued in operation for a year and a half, transmitting 12 horse power to 100 looms.

The difficulties of the flat band suggested round wire ropes; these were accordingly substituted, and were placed upon the same wooden pulleys, which however were first grooved to the depth of $\frac{1}{2}$ inch. This plan answered every expectation, and is still in operation; and experience having fully sanctioned its use, a second wire rope was soon put in operation, transmitting the power to a distance of 256 yards. The two pulleys were each 9 ft. 6 ins. diameter, making $91\frac{1}{2}$ revolutions per minute, and a steel rope

$\frac{1}{2}$ inch diameter was employed, transmitting 50 horse power at a speed of 31 miles an hour.

In this instance it was found necessary to have supporting pulleys to prevent the rope from trailing upon the ground. These carrying pulleys, shown in Fig. 8, Plate 14, were placed half way between the transmitting pulleys, or 128 yards apart, and in the first instance they occasioned very great difficulties by the rapidity with which they were worn out in the groove. They were constructed successively of copper, wood, and polished cast-iron, and were also faced with leather, horn, india-rubber, lignum-vitæ, and boxwood. All these failed however, the facings were soon worn out, and when the groove was of metal or hard wood, and did not itself wear, it destroyed the rope.

After repeated experiments a dovetailed groove was formed in the bottom of the pulley groove, and filled with gutta-percha, as shown one third full size in Fig. 9, Plate 14. This turned out a perfect success, and carrying pulleys thus faced have an almost unlimited amount of durability. Soft willow wood is also now used with great success for the large transmitting pulleys; the mode of putting the wood into the groove is shown in Figs. 6 and 7, Plate 14.

In all cases it is necessary for the ropes to run on a cushion of wood or gutta-percha. On such a cushion the rope runs without any noise or slipping whatever, soon wearing a small round groove for itself in the face; and the rope is found to last for two years and upwards. Ordinary wire ropes will not answer; they must be made specially for this system, and must be very tough and flexible; steel wire is principally used. In splicing the ropes, a long splice of 4 or 5 yards length must be used, as by this means the rope is not weakened, nor is its size increased; and if this splice is well finished, only a practised eye can detect its locality. The diameter of the ropes is proportioned to the force to be transmitted, the actual sizes having been determined by practical experience. The speed of the pulleys at the circumference is from 30 to 80 feet per second, but has been carried as high as 90 feet per second, or

60 miles an hour. Running at this high speed it is advisable for the wheels to be cast in best steel, as iron pulleys at this velocity incur a danger of flying to pieces from centrifugal force.

The deflection or "sag" of the ropes is illustrated in the diagram Fig. 5, Plate 13, in which the upper rope is the pulling rope, and the lower the trailing rope. When in work, the tension in the upper rope is just double that in the lower rope; the latter consequently dips much lower below a horizontal line than the upper one. When the rope is at rest, it occupies the position shown by the curved dotted lines. To ascertain in the first instance the length of rope required, it is usual to suspend a single wire in the position the rope is to occupy when at rest, hanging it so that the deflection A below the horizontal line is about 1-35th of the whole span from wheel to wheel. The deflection B of the upper driving rope will then be about 1-45th to 1-50th of this span; and the deflection C of the lower rope is on an average one half greater than the deflection A of the rope at rest.

It is required sometimes to change the direction of transmission of the power at some point in its course, either in order to avoid an obstacle, or for the purpose of distributing the power to a number of consumers. For this purpose the directing pulleys shown in plan in Fig. 10, Plate 14, are used at Loyelbach; but the best method has been found by experience to be the use of bevil wheels, as shown at D in the plan, Fig. 3, Plate 13, by which the direction can be changed at any angle.

Experience has proved that the loss of power sustained in this system of transmission is very trifling, and it arises from three sources:—

1st. The resistance of the air against the arms of the pulleys.

2nd. The rigidity of the rope in its passage over the pulleys.

3rd. The friction of the pulley bearings.

The total loss thus sustained in short transmissions, if intermediate supporting pulleys are not used, does not amount to more than $2\frac{1}{2}$ per cent. For example, two pulleys 12 feet diameter, making 100 revolutions per minute, with a rope 0·4 inch diameter running at a speed of 63 feet per second or 43 miles an hour, will transmit

120 horse power to 150 yards distance, without occasioning a loss of more than $2\frac{1}{2}$ per cent. or 3 horse power. But when the distance requires supporting pulleys, then each of these will add its portion to the amount of loss in transmission. These supporting pulleys of cast-iron 6 feet diameter for transmitting 120 horse power are about 330 lbs. weight, and to this has to be added the weight of wire rope supported, which is about 165 lbs. for every 157 yards or the distance between the supporting pulleys; thus making a total of 495 lbs. bearing on each axle of 2 inches diameter. Now at a speed of 134 revolutions per minute or 29 miles an hour there results for each pulley a loss of about 36 foot-lbs. per second, equal to 1-15th horse power; and as there are seven pairs or fourteen supporting pulleys to 1100 yards distance, the employment of these pulleys occasions a loss of nearly one horse power for every 1100 yards. Supposing it is desired to transmit 120 horse power to a distance of $12\frac{1}{2}$ miles or 22,000 yards, there will be first the loss of $2\frac{1}{2}$ per cent. or 3 horse power for the friction of the large driving pulleys, and then a loss of nearly 1 horse power for every 1100 yards or 20 horse power in the 22,000 yards, making a total loss of 23 horse power; which still leaves an available power of 90 horse power, after making a further allowance for the resistance of the air and the rigidity of the rope. To perform the same amount of work by iron shafting would require not less than 3,000 tons weight of material in motion.

The largest example of this mode of transmitting power, out of about 400 cases now in operation, most of which are in America, is at the works constructed and used by the Wasserwerk-Gesellschaft in Schaffhausen on the Upper Rhine, and is illustrated in Figs. 1 to 4, Plates 12 and 13. The plan in Fig. 1 shows the river Rhine, the weir E, the turbine house F, and the position of the different buildings in the town of Schaffhausen to which the ropes J J convey power. Fig. 2 is a corresponding section along the line of the river.

At the part H, Fig. 1, the river flows over a rugged and torn rocky bed; the quantity of water during the rainy season is very

great, but is very considerably diminished during the summer season. It had been long in contemplation to utilise the power of the water at this point; but the enormous difficulties and great cost of the undertaking prevented the attempt, until the formation of the present company, which is due to the energy of Mr. Heinrich Moser of Charlottenfels near Schaffhausen. In consequence of the difference of rise and fall in the river level during summer and winter, it was found necessary to construct a weir dam E, 612 feet long, which crosses the river in a zigzag direction so as to take advantage of the most favourable ground in the river bed. This dam raises the natural level of the upper water about 6 feet, and ensures always a sufficient supply. On the completion of this dam the old river dams, which led the water to old water wheels on the north side of the river, were removed; and a large sluice-gate is fixed at G at the north end of the new dam.

The Turbine House, Figs. 3 and 4, Plate 13, shown to a larger scale in section and plan in Figs. 11 and 12, Plates 15 and 16, is built of dressed ashlar, and is situated on the south side of the river; it is 64 feet long by 34 feet wide, and the two stone side-walls are carried up to a height of 13 feet above the top of the weir dam. The outflow canal K, Fig. 11, from the bottom of the turbine house is about 700 feet long by 20 feet wide, and has a fall of about 16 feet in its length; it is driven in the bed of the river, as shown by the dotted lines at K in the plan, Fig. 1, and forms a conduit in the rock, being covered with a water-tight roof of heavy planking so as to preserve always a free discharge for the tail water. The two ends of the turbine house are closed by wood planking, with sluice doors A A, Fig. 11, which slide between wrought-iron frames, and allow the water to enter from either the upstream or the downstream end of the turbine room. A wrought-iron grid B is fixed in front of each sluice, to prevent the entrance of the roots, trees &c., that are liable to be floated down the stream. On a line with the arch of the outflow canal K is a strong floor C, carried on four cast-iron columns; and in this floor are fixed circular cast-iron frames for supporting the turbine boxes D.

The Turbines, three in number, are each $9\frac{1}{2}$ feet diameter, and are fixed on vertical wrought-iron driving shafts 8 inches diameter. They are driven by a fall of water varying from 12 to 16 feet according to the quantity of water in the river, and are capable of developing collectively about 750 horse power; the three turbines use with a 12 feet fall about 600 cubic feet of water per second, but this can be increased to 850 cubic feet during periods of flood. Their average speed is about 48 revolutions per minute, giving a circumferential speed of 24 feet per second.

Each of the three turbines is in two parts, as shown to a larger scale in the vertical section, Fig. 13, Plate 17; the upper stationary portion E contains two concentric rings of oblique blades, by which the descending water is directed against two corresponding rings of oblique blades inclined in the opposite direction in the horizontal revolving wheel G below, which is keyed on the vertical driving shaft. When the water in the river is low, there is a greater difference of level between the upper and lower water, and consequently a greater fall for driving the turbines; and at that time the outer ring only of each turbine is employed, the inner ring being completely closed. But when the water is high in the river and the fall consequently is not so great, both of the turbine rings are opened. The centre of the upper directing portion E of each turbine is closed by a fixed bell, in which is provided a bearing for the turbine shaft, lined with wood strips. Each turbine shaft is carried by a compound collar-bearing H at the upper end, from which the whole weight of the turbine is suspended; and this bearing is carried by a pair of cast-iron girders, which are fixed across the turbine house, resting on the side walls. An intermediate bearing is given to each turbine axle in a longitudinal girder L, Fig. 11, which is supported by iron stancheons M between each of the turbines. This bearing is lined with wood strips, and above it a collar N is fixed on the turbine axle with clamping screws, and is adjusted so as to be just clear of the bearing in ordinary working; but when the water pressure becomes very great, a slight settlement of the turbine shaft takes place, and this collar then takes a bearing and supports part of the weight, so as to prevent too great friction in the compound collar-bearing H at the top.

The supply of water to the turbine blades is regulated by two cover rings P and Q, Fig. 13, Plate 17, which can close the two rings of openings in the upper directing apparatus E. The outer cover ring P is suspended by six spindles, which are screwed at the top through nuts in the spur wheels R. These are geared together by a large centre wheel, so that they can be all turned together by gearing from the hand wheel S, Fig. 12, by means of which the cover ring can be raised or lowered to adjust the opening for the passage of the water, and so regulate the speed of the turbine. Only the outer portion of the turbine is ordinarily used; but when the inner ring of blades is required to be also used in the case of diminished pressure of water, the inner cover ring Q is raised by screwing up the outer ring until it catches three projecting brackets which are fixed on the inner ring, and the two rings are then lifted together, as shown in Fig. 13. The three turbines can be separated from each other by sliding down wood planks into grooves in the centre stancheons M and corresponding grooves in the side walls of the turbine house.

The power of the turbines is transmitted to the horizontal shaft T, Figs. 11 and 12, by bevil wheels, each of which slides upon a feather in the turbine axle, and can be lowered out of gear when required by means of a screw and hand-wheel at the top, as shown in Fig. 13. At the end of the horizontal shaft T are carried two large grooved pulleys U U, 15 feet diameter, by which 540 horse power is conveyed across the river to a building on the north bank at L in the plan, Fig. 1, Plate 12, a distance of 370 feet. The ropes crossing the river are shown to a larger scale in Figs. 3 and 4, Plate 13. From the point L, Fig. 1, the direction of the ropes is carried up the river nearly at right angles for a distance of nearly 1500 feet, when another change of angle takes place at M; and this distance is subdivided into three sections of about 500 feet each. From M to N is another distance of nearly 1500 feet, using about 400 horse power; and the total length of main transmission is thus about 3300 feet. The power is transmitted from station to station by wire ropes $\frac{3}{4}$ inch diameter, made of the

best Swedish iron, 72 wires to the rope; these ropes last from $1\frac{1}{2}$ to 2 years. Each rope is of sufficient strength to transmit the whole power, but two ropes are used, so that in case of an accident to one of them, the other will be enabled to carry on the work without interruption. The pulleys run at an average speed of 100 revolutions per minute, or 53 miles an hour. The total number of transmissions of power to various factories is at present seventeen.

The transmission of this power by single ropes from the turbine house would have entailed the use of wheels of very large diameter, which would have caused much inconvenience; but in dividing the power between two ropes, it was feared lest the strain might not be equally shared between them. This became a matter of serious consideration, but was ultimately overcome by the ingenious compensating arrangement formed by the differential gear shown at V in Figs. 11 and 12, Plates 15 and 16. It consists in leaving the rope pulleys U free to run between collars on the main shaft T, and placing between them at right angles to it a strong transverse arm keyed upon the shaft, and carrying on each side of the shaft a bevil wheel, also free to run between collars on the transverse arm; these wheels gear into bevil wheels fixed upon the bosses of the rope pulleys U. The power is thus applied by the main shaft to the rope pulleys through the teeth of the bevil gear, and if the ropes are each doing an equal share of work no perceptible motion takes place between the bevil wheels, the same teeth remaining in contact; but on any irregular strain taking place on one of the ropes, the wheels on the transverse arm will move forwards a little upon the wheel fixed to the retarded pulley, and a compensation is thus immediately effected.

A governor W, shown in Fig. 11, Plate 15, is connected by a shaft with the gearing of the lifting screws R that regulate the supply of water to the turbines, so as to ensure a uniform rate of speed being maintained; and a large break wheel X with a friction strap is fixed upon the main shaft T, and is acted on by a self-acting safety apparatus so as to prevent any excess of speed occurring. Guide cheeks Y are fitted over and under the rope pulleys U, to prevent the ropes from getting out of the grooves.

This system of power transmission works admirably in practice, and has proved a perfect success; and the cost at which the water power is now let out to the consumers is about 40 per cent. below the cost of steam power. For the particulars of these Schaffhausen works the writer is indebted to Messrs. Rieter, engineers, of Winterthur, by whom the works were erected.

Mr. C. W. Siemens observed that the transmission of a large amount of power from a natural source to distant points where that power could be used was certainly a very interesting matter; and it was evident that by running an iron or steel wire-rope at a velocity of from 30 to 60 miles an hour over large pulleys, transmission of power could be effected with very little loss. The works at Schaffhausen described in the paper, which he believed were as yet the most important of the kind, were carried out, as far as he knew, with perfect success. Similar works he understood had lately been established at Bellegarde in the Rhone valley by Mr. Ellerhausen, and 1000 or 1500 horse power was transmitted to a distance of more than a mile, crossing the Rhone twice. With regard to the wire ropes referred to in the paper, which he presumed were composed of iron or steel wires and hemp, it would be interesting to have some particulars of their actual construction; and he enquired whether the splicing was done in such a manner as to give no increase of size at that part, and so as not to introduce an element of stiffness or of weakness in the rope in passing round the pulleys. For the bearing surfaces of the pulleys it had been stated that wood was employed, and also gutta-percha; leather he believed had also been used in other instances, and he should be glad to know which material really answered best. Any one of these soft materials he supposed would answer the purpose of preventing chafing of the rope in passing round the pulleys.

Mr. J. Lee Thomas mentioned that during a visit to Portugal last summer he had seen this system of transmitting power by wire

ropes in operation at one of the mines in the extensive lead-mining district of Aviero, about thirty miles south of Oporto. The locality was one in which water power from a river was available for pumping and drawing at most of the mines; but in the case of one mine, Coval da Mo, the nearest point of the river was almost a mile distant from the main pumping and drawing shaft; and as a hill of considerable elevation intervened, it was not practicable to construct a mill race or launders for conveying the water to the mine. It had therefore occurred to the manager of the mine, Mr. Francis Feuerheerd, that the adoption of the wire-rope system would be advantageous; and having satisfied himself of its practicability by the experience obtained at Schaffhausen, and also at Bellegarde on the Rhone, where large water-power works were being constructed on the same system with turbines and ropes, he had erected similar machinery for the mine, which last summer had already been at work some months, and had since been in continued operation, and answered most successfully. Valuable as such a method of transmitting power might be in the case of manufacturing industries, it appeared of even greater value for application to mining operations, inasmuch as these had of necessity to be carried on at the locality of the mine itself, and could not be taken to the source of power; but a factory, if other considerations did not interfere, might be established close to the source of power. At Coval da Mo mine the power transmitted by the rope was already employed for pumping and drawing, and it was intended to put up dressing machinery to be also worked by the same power. The pulleys were approximately 15 feet diameter, were about 250 feet apart, and were fixed on substantial piers of masonry; and the ropes used were steel wire ropes of $\frac{5}{8}$ inch diameter. The groove of each pulley was lined with pieces of leather placed edgeways, about 5-16ths inch thick or less, which were cut out of the hide with a stamp, and were readily fitted by a common millwright into the dovetailed channel at the bottom of the groove; this lining for the grooves of the pulleys was found to answer well. An electrical communication was provided from the mine to the turbine, by which by means of

a counterbalance weight the water could at any time be shut off from the turbine, if anything went wrong at the mine. At Bellegarde he believed there was a self-acting arrangement for stopping the machinery automatically in the event of a breakage occurring.

The PRESIDENT enquired what amount of power was transmitted by the ropes at the mine in Portugal, and what was the speed at which they were run.

Mr. J. LEE THOMAS believed that with a full supply of water, such as would be obtained in the winter season, about 100 horse power would be transmitted; and the speed of the ropes was about 30 miles an hour. The direction of the ropes was changed once between the turbine and the mine, the change being effected by bevil gearing.

Mr. W. ANDERSON mentioned that in the case of slow-running wire ropes driving large cranes he had found the ropes wore out in about the same time that had been named in the paper,—two years; and judging from the experience with the cranes, he saw no reason why the application described in the paper should not prove a good and durable one. The most serious trouble in using wire rope for working cranes had been the occasional stranding of the rope from defective workmanship; sometimes a rope that appeared a good one had been destroyed after a few days' use in consequence of a single strand giving way. The ropes described in the paper having been specially stated to be of very superior quality, he inferred that some difficulties had arisen, and enquired whether any inconvenience had ever been experienced from stranding; where a number of factories depended upon the power transmitted from a common prime mover, the occurrence of such accidents might prove a very serious drawback to the usefulness of the plan.

Mr. A. PAGET observed that in the pulleys shown in the drawings the rope did not seem to get any grip upon the sides of the groove by wedging itself into the **V**, as it rested wholly upon the bottom of the groove. In most cases of transmitting power by ropes on a comparatively small scale, as in the use of hemp rope or gut for

driving machinery, the rope was expected to bed in the V without touching the bottom of the groove; and in hoists where the V pulley was used he found that the power of the rope was much increased if it was not allowed to rest on the bottom of the groove. He supposed the reason of the difference in the case of wire rope must be that a wire rope would not stand the same treatment as an ordinary hemp rope; and he should be glad to know what the effect of such treatment upon wire rope had been, and whether it had been tried to be remedied by the use of wood or gutta-percha as a lining at the sides of the groove for the rope to rub against.

Mr. J. Robinson thought that, as the great length of span and consequent tension of the rope gave it sufficient adhesion upon the wood lining in the bottom of the grooves of the pulleys, for transmitting the necessary power without slipping, it would be only detrimental to let it bear against the sides of the grooves, because the friction so occasioned between the rope and the pulley would have a tearing action upon the rope; and it seemed better therefore to let the rope touch the bottom of the groove only, without touching the sides.

Mr. A. Paget suggested that with the increased adhesion consequent upon the rope bearing against the sides of the groove there might be a possibility of reducing the speed; if the same adhesion could be got at 30 miles an hour as at 60, that would be an advantage in itself. It might however be the case that the wearing action of the pulley upon a rope bearing against the sides of the groove would counterbalance any advantage to be gained from a reduction of speed; and he wished to know if the experiment had been tried.

Mr. R. H. Tweddell enquired how the exact indicated horse power at the turbine end of the rope had been ascertained; and how the loss of power in transmission had been arrived at, which had been stated not to exceed $2\frac{1}{2}$ per cent. in this case, and 1 horse power additional loss for each 1100 yards distance of transmission.

Mr. W. R. Browne mentioned that he had been connected some time ago with an application on a small scale in this country of the

same principle of transmission to what was perhaps one of the most difficult kinds of engineering work, the removal of rock under water in a tidal river. This was in the bed of the Avon at Bristol, where it was required to get rid of some rock in the bed of the river, from 4 to 8 feet under water at low tide, and covered at high tide with about 30 feet of water, and always covered by from 4 to 6 feet of extremely soft mud. Getting away rock under these circumstances was by no means an easy matter; and the plan adopted in this instance was to make a temporary cofferdam in the mud, round the portion of rock to be removed, then to clear the mud off it, and blast the rock in the ordinary way. To do this it was necessary to lay the rock dry every tide by some mode of pumping, as soon as the water had fallen below the top of the cofferdam; and it was therefore desirable to have such a mode of pumping as would get rid of the water with the greatest possible speed. To work any ordinary kind of pump in the river in such a position would have been a very difficult matter; power was therefore provided by means of a portable engine placed on the bank of the river about 30 yards from the spot where the work had to be done. Within the cofferdam was placed on the bottom a screw pump, constructed of an Archimedean screw, which was the first he believed that had been made on the plan advocated by Mr. Airy some years ago; the thread of the screw was made of wrought iron. It was driven by bevelled wheels from a pulley mounted on the pump frame, and this pulley was driven by an ordinary hemp rope from a similar pulley mounted on the engine crank-shaft on shore, the two pulleys being simply lagged with wood; this mode of driving the pump was free from all difficulty, and had proved completely successful. Directly the water was off the dam, the pump was started to work, and began immediately to clear out not only the water but also the mud, the great advantage of that sort of pump being that everything passed through it. The other difficulties however connected with this mode of removing rock in such a position were found so serious that the plan was not persevered in very long; but so far as concerned the mode of transmitting the power, and of pumping

the water out in so short a time, it answered every requirement; and he thought there were other positions in which it might perhaps be found useful.

Mr. E. J. C. Welch considered the difficulty which had been alluded to in the use of wire ropes running over pulleys, from a strand of the rope giving way, was caused by the ends of the wires not being properly finished in spinning the rope. As each bobbin of wire ran out in the spinning, it was necessary that the wire on the next bobbin should be properly attached to it; this was often done by merely twisting the new wire round the previous one, which was a very unsatisfactory method, because the twist was liable to come open and allow the loose ends of the wire to protrude; the better plan was to braze the ends of the two wires together by a small gas blow-pipe, so as to make the whole length of the wire continuous. It seemed to him however that the mode of transmitting power by wire ropes was not the most economical; were the turbines used to drive a set of force pumps and force the water through small pipes under high pressure into an accumulator, he thought the power could in that way be distributed to much greater advantage. The wear and tear of the pipes would be something inappreciable in comparison with the great wear and tear of the wire ropes, to say nothing of the friction of the pulleys and other portions of the apparatus. If the power were utilised on a hill, or at a greater height than the position from which the water was forced, there would be a certain loss in the first instance, because the water would have to be forced up to that height before any power could be realised. But this objection might be got over by allowing the waste water from the various machines worked to return down the hill, and drive an engine which would assist in driving the pumps; so that the only power which would be absorbed would be that actually used in driving the various machines, and the advantage would be recovered of a fall from the height to which the water was raised.

Mr. C. C. Walker remarked that the utilisation of the natural forces which were flowing away unused was a matter of very great importance, and the plan described in the paper was one of the

modes that had been introduced for that purpose. These forces would have been more extensively used long ago, but that other sources of power were more convenient and cheaper of application; and if the means of communication between the power and the work to be done could be simplified and cheapened, natural sources of power would doubtless be used extensively. With regard to the statement that the cost of transmitting power from the river by means of turbines and wire ropes was 40 per cent. below that of steam power, he should be glad to know how this estimate was arrived at: in order to ascertain the comparative cost for other places where such water power existed, it was necessary to know the value of the coal or other fuel used for steam power on the spot where the power was applied, because it was only the power which was the cheapest and most reliable and convenient that would be used. He enquired also whether the company owning the water-power apparatus at Schaffhausen was composed entirely of the users of the power, as this was an element in the prime cost of the power.

Mr. J. McFarlane Gray enquired what proportion of the cost of the water power was due to wear and tear, and what to interest upon the original outlay. The cost of steam power was usually estimated per indicated horse power per hour, which gave simply the running expense; but what he wished to arrive at in the present instance was the separate cost of wear and tear, and of interest upon the original expenditure.

Mr. P. G. B. Westmacott mentioned that the plan of transmitting power to a distance by water pressure had been carried out by Sir William Armstrong for the lead mines at Allenheads in Northumberland, where the fall of water in the river was utilised to drive water wheels, which worked force pumps for charging accumulators, and the high-pressure water was conveyed in pipes to a distance for working the machines at the mines. He had not sufficient data to make any comparison between that system and the one described in the paper; but certainly in transmitting power to a long distance by water pressure some of the defects attending the use of ropes were got rid of, particularly with regard to the wear and tear.

The PRESIDENT expressed a hope that a paper would be given at some future meeting of the Institution on the interesting and important subject of hydraulic transmission of power.

He wished to know what was the actual cost at which the water power was developed at Schaffhausen, which was stated in the paper to be 40 per cent. below the cost of steam power. He asked also how the amount of power taken by each factory was assessed; whether at all times upon the maximum power that could be taken into the factory in full work, or whether some percentage of that full power was taken. The manner in which the final transmission of the power was made to the different factories had not been described in the paper; at the time that he visited the works in 1869, when there were only two of the turbines in operation, with a place provided for the third, the driving shafts to the different factories were he believed brought under the footways of the streets. At that time also the ropes were not carried on any supporting pulleys, strictly so called, such as those described in the paper as in use at Loyelbach; but a succession of separate ropes went from pulley to pulley in single spans, there being on each axis a pulley to receive motion and a second pulley alongside, from which another rope started off to the next station beyond.

Mr. W. SMITH believed that as early as about 1837 wire ropes had been in use in certain places in this country for transmitting power to long distances by his father, the late Andrew Smith, the first maker of wire ropes; and about 1840 an endless wire rope driven by a stationary engine was employed for towing boats on the Regent's Canal, London, along a distance of about $3\frac{1}{2}$ miles, part of which was through a tunnel. The rope was supported on posts at intervals of from 100 to 150 feet along the bank of the canal, and the power was utilised by the bargemen throwing a tow line from the boat over the running rope; and when they ceased to require the assistance of the rope, the line was simply loosened off from the bollard on the boat. That plan, experimentally in use for a considerable time, was tested against the screw propeller, the duck-foot propeller, and various other forms of propelling apparatus in a steam tug, but it was not found

economical. He had also seen many other cases in which rapidly running wire ropes had been used for the transmission of power, and the "fly rope" of an ordinary ropery was a familiar instance; the eqnaliser, as it was called, for drawing out the yarns, was drawn along the ropery by means of the "fly rope," which also communicated motion to the gearing through a whelp wheel, and thereby to the spindles for twisting the strands; this old system of rope-making had however been for some time obsolete, and vertical or horizontal machines containing bobbins had been substituted for it. The power of turbines had been transmitted by wire ropes for a good many years past. It appeared to him that the principal feature in the application described in the paper was the high velocity at which the ropes were run; and this he thought might be a point of importance where the rope was constantly doing an amount of work proportioned to the power transmitted and the wear and tear.

Mr. Morrison said that, happening to be in Schaffhausen recently during the time that coal was at such a high price, he had been very much struck with this mode of utilising water power, which was the first application of the kind that he had seen; and he thought this notice of the subject might be the means of directing attention to a mode of utilising with advantage the large amount of power now going to waste in many of the mountainous districts in this country.

With regard to the construction of the ropes, these were composed of six outer strands of twelve wires each, twisted round an inner core of hemp, so that there were 72 wires in the rope. From enquiries that he had made he understood there had never been any difficulty experienced from the stranding of the rope; in respect to this point a great deal depended upon the make of the rope and the tempering of the wire put in it. It was only the fine makes of wire rope that contained as many as 72 wires in $\frac{3}{4}$ inch diameter, and by using such a number of wires the rope could be laid together very compact, so as to be almost like a round bar; the individual wires then lay so close together that there was

barely any possibility of the spliced ends getting out and breaking up the strands. In America the ropes used in transmission of power, of which there were now about 400 examples, were made still finer and closer, and had as many as 135 wires. The splicing of the ropes was done by hand, but he was not able to describe the process completely; at a future meeting he hoped to exhibit specimens of the ropes, showing exactly how the splice was made.

As regarded the lining of the grooves of the pulleys, from the enquiries he had made he had ascertained that nothing had been found to succeed so well as willow wood. The continual passage of the rope round the pulley seemed to put a sort of hard glaze upon the wood, and at the same time gave the rope a sufficient amount of adhesion upon the pulley, without any need for the rope to be gripped either by the groove of the pulley itself or by the special clips introduced in Fowler's clip-drum, which he thought answered admirably in other cases.

Respecting the actual cost of this mode of transmitting power, he had not at present been able to get any further information than that given in the paper; but he hoped on a future occasion to be able to furnish the complete particulars that were desired.

Sir JOHN COODE enquired whether the ropes employed at Schaffhausen had any coating given to them to protect them from the action of the atmosphere. At the Portland breakwater he had had wire ropes in daily use for fifteen years for hauling on an inclined plane, where they were exposed to an atmosphere near the sea and frequently charged with saline particles; and it had been found not only desirable but necessary to paint them with Stockholm tar and linseed oil to prevent oxidation. Not only did this protect the rope from atmospheric action, but in a short time it formed a thick glutinous coat on the lagging of the drums, which made a nice soft cushion for the rope to bed upon, and the impression of every wire of the rope could be seen in it; it also increased the adhesion of the rope upon the drums.

Mr. MORRISON said that the wire ropes used at Schaffhausen when newly made were soaked for several hours in a steam-jacketed

cistern of wood tar entirely free from acid; and the same tar was afterwards applied to the ropes regularly three times a week to prevent oxidation of the wires.

Mr. T. Hawksley observed that an important point to be considered in regard to the transmission of power by ropes and pulleys, or by water pressure through pipes, was the relative amount of friction in the two cases. As the friction of water through pipes increased as the square of its velocity, while the friction of ropes increased only in the simple ratio of the velocity, there must be some speed at which the two resistances would equate exactly with each other; after that speed had been reached, water transmission would be less effective than rope transmission, but below that speed the contrary would be the case. For the purpose therefore of arriving at the relative merits of the two plans, the particulars of the friction ought to be accurately ascertained.

Mr. C. W. Siemens pointed out that there was also another difference between the two modes of transmitting power by rope and by an accumulator; namely that in transmitting by rope there was only one prime mover, but in transmitting by an accumulator there were two prime movers, involving two losses of useful effect.

The President remarked that the paper which had been read brought to notice a practical application to manufacturing purposes of that which might be called one of the forces of nature. He feared that the possibility of making such applications did not as a rule receive the consideration from engineers which the subject deserved; and seeing that at Schaffhausen there had been in existence since 1866 this utilisation of the otherwise waste power of the Rhine, he thought it was well that it should be brought to the knowledge of English engineers, as they might thereby have their attention directed to the question. When on the spot in 1869, he found a considerable power was being given out to the town through the turbines, two of which were at that time fitted and at work; he was told that the power so obtained was readily taken up by the manufacturers, and that the best results were being realised from the plan. It had been said that if this mode of obtaining power were only

as cheap as the employment of coal for that purpose, no good was done by its adoption; but in that view he did not agree, for it seemed to him that if it were possible to get power, even at the very same cost as attended the use of coal, but from a source which did not consume fuel, it was desirable to do so, leaving the fuel for those purposes for which heat was an essential, such as metallurgical operations and domestic requirements. It would be well that every other source of power should be exhausted before wasting coal; and he thought therefore the question of the best mode of transmitting power from natural sources was a most important one. In addition to the method of transmission described in the paper, by means of quick-running ropes, power could be transmitted by shafting, by water pressure, by compressed air, and also by exhaustion of air, according to the plan originally proposed by the late Mr. John Hague, who did actually many years ago convey power to considerable distances by exhaustion. That method necessarily involved the disadvantage of a very low effective pressure, but it was worthy of remembrance as the first step towards the transmission of power from a distance; Mr. Hague used often to speak of the vast amount of power going to waste in the waterfalls of Cumberland and of other hilly districts because it would be inconvenient to utilise it by establishing factories in such situations, and he had large ideas as to how that power might be utilised by transmitting it by means of exhaustion of air.

On a future occasion they would be glad to have the present paper supplemented by some further information respecting the various points of detail that had been enquired about in the course of the discussion, for detail was the very life of mechanical engineering. He moved a vote of thanks to Mr. Morrison for his paper, which was passed.

The following paper, communicated through Mr. Richard Taylor, of London, was then read:—

ON ROCK DRILLING MACHINERY.

By Mr. Thomas B. Jordan, of London.

Amongst the various ingenious Rock Drilling Machines which have been constructed during the gradual development of the application of power to the most arduous portions of miner's work, there are some in use that have established a reputation, and others that make a fair exhibition of work, but involve points of construction which in the writer's opinion are decidedly objectionable in this class of machinery. Elaborately constructed and highly finished machines are not the most suitable for the purpose; they will certainly work with great precision and perfection so long as they retain their original adjustments and are driven by a competent workman; but these are not the machines which will eventually hold the highest place in the estimation of mining engineers. What is wanted is a strong simple compact machine, without external gearing or any fine parts liable to injury or derangement. All small levers and jointed gear are objectionable, because they must be rapid in action, and the dirt and grit which it is impossible to avoid in underground working give rise to rapid wear of the many joints of the gearing; and they then lose the accuracy of adjustment which is essential to their efficient performance.

This may be illustrated by reference to a machine now in extensive use in Germany, which the writer has had under his own charge in carrying out a long series of experiments. The "Sachs" Rock Drill, shown in Figs. 17 to 20, Plate 22, is a specimen of refinement in construction, and is fitted with all the means of perfect automatic action; it has been and still is used in executing extensive works, and has made a good name for itself, but still appears to the

writer to be open to the above objection. Nothing can work better than this drill, so long as it retains its original perfection; but in order to maintain this condition it must return to the fitting shop very frequently, and therefore is not suitable for mining under ordinary conditions. In many of the mines where it is used an engineer's shop forms a part of the establishment, and the machines are made on the spot in some cases, and there is always a spare machine or two in stock so as to keep the machines in order without any stoppage of the work underground. Under these favourable conditions the Sachs drill can be used with advantage by a competent and careful driver.

Another very important consideration in the construction of rock drills is the clearance space at the end of the driving cylinder. There are some machines in use in which this space amounts to as much as the cubic content of the stroke, or even more; in such cases they of course use double the quantity of compressed air that is requisite to produce a given result. In an experimental trial these machines produce a good effect, but the cost at which they do it is not considered until they come into practical work.

The weight and size of the machine, and the means of fixing it in any required position, are also elements of great importance. A large heavy machine and cumbrous stand in a narrow level may cancel all the advantage that can be derived from mechanical drilling; and the writer's practice has therefore been to arrange the construction so that one man may be able to carry and fix the machine, and the other to carry and fix the stand. Of course this limitation applies only to the driving of ordinary levels in metalliferous mines; in sinking large shafts, or excavating railway tunnels and quarries, other conditions come into play, and the means must be modified to suit the work.

The question of how to construct all the plant requisite for the economic application of power to the underground work of mining is not yet fully worked out, although many clever machines are in use, and the subject has been worked at by many clever mechanicians, and has passed through the course of complicated and refined detail, which in turn is being cleared away

bit by bit, until the ultimate rock-drilling machine will be found in the most simple elements of all its predecessors. All the machines have had cylinders and pistons and piston-rods in a greater or less number of pieces, in combination with an endless variety of valves, and gearing for actuating them; and these valves and gearings have been fruitful sources of trouble and expense. But the remedy for all these objections has now been arrived at by the simple and certain plan of dispensing altogether with both valves and gearing.

Darlington's Rock Drill, which forms the special subject of the present paper, is without a valve of any kind, and it has no substitute for a valve; hence there is no occasion for any gearing to alternate the pressure to opposite sides of the piston. The advantage of getting rid of these parts is at once apparent when the fact is considered that the machines may work up to 1000 blows per minute, and are liable to be splashed with sandy water, and subject to the inevitable dirt of mining operations. Under such conditions it is evident that the most simple machine which will do the work must be the best, for every joint and every slide is a source of wear and derangement; therefore the omission of the valve and all its gearing at once gets rid of endless trouble, and the cost and delay of perpetual repairs.

This machine is shown in the longitudinal and transverse sections, Figs. 1 to 5, Plate 18; and specimens of the separate parts are exhibited. It consists of two parts only, which are essential to the development of its power; one piece is the cylinder A with its cover, and the other the piston B with its rod. The cover when bolted on forms a part of the cylinder; and the piston-rod is cast solid with the piston, and is large enough to receive the tool at its outer end. These two parts constitute an engine, capable of making from 300 to 1000 blows per minute; and with less than one fixed and one moving part it is of course impossible to develop power in a machine by the action of an elastic fluid. That the requisite power can be developed by these parts is proved by the fact that this tool drills holes in hard granite at rates varying

from 2 to 7 inches per minute when the driving pressure of air is under 50 lbs. per square inch.

The piston itself is made to do the work of a valve in the following manner. The annular area for pressure on the front of the piston, Fig. 3, Plate 18, is very much less than the area of the cylinder, and can be made to bear any desired proportion to it by altering the diameter of the piston-rod. The pressure from the pipe C is always acting on the front of the piston, and therefore when there is no pressure on the other side the piston must move backwards in the cylinder, and in doing so it first covers the exhaust port D, Fig. 1, and next uncovers the equilibrium port E which communicates between the front and back ends of the cylinder; but before doing this it has been put into rapid motion, and therefore continues moving in the same backward direction until the pressure on the larger surface has overcome the momentum, and given it motion in the opposite direction. The forward stroke is made by the pressure on the difference of area between the two sides of the piston, or in other words by the pressure on the area of the piston-rod. Owing to the length or thickness of the piston, the exhaust port D is never open to its front side; but in the forward stroke, it is opened almost directly after the equilibrium port is closed, and nearly at the time of striking the blow. The full double stroke is often made in the thousandth part of a minute; but in the ordinary course of working the rate is from 600 to 800 blows per minute. It follows from the mode of action just described, that the air used in making one double stroke is only that requisite to fill the back end of the cylinder before the equilibrium port is closed; because the amount employed to make the return stroke is not expended. The actual quantity of air which is expended in making one stroke of the full length in the drill shown is 33 cubic inches, and the effective driving force on the piston with air of 40 lbs. pressure per square inch is 160 lbs. The quantity of air used is an element of great importance in the construction of all machines driven by the expansive action of compressed air, seeing that it is of necessity a much more expensive power than steam.

The contrivance for rotating the drill is inside the cylinder, and therefore protected from grit and dirt. It consists of a spiral or rifled bar H, having three grooves, and fitted at its head with a ratchet wheel G, which is recessed into the cover of the cylinder; two detents J J, Fig. 5, also recessed into the cover, are made to fall into the teeth of the ratchet wheel by spiral springs, which in case of breakage can be renewed immediately without taking off the cover. By this arrangement it will be seen that the spiral bar H is at liberty to turn freely in one direction only, being prevented by the detents from turning in the other direction. A long recess in the piston receives the spiral bar, and is fitted with a steel nut that accurately fits the grooves of the spiral. The piston in its instroke is thus compelled to turn upon the fixed bar; but in its outstroke it turns the bar, because the ratchet leaves the bar at liberty to turn in the direction in which the straight outstroke of the piston tends to rotate it, and it thus assumes a new position, so that the piston in the next instroke is again turned further forwards in the same direction as before.

There is one detail in the construction of this drill, which, although common to several others, has so often been questioned, that a few words may here be said in its defence. The piston is without packing of any kind, and packing cannot be used in it because it has to pass the exhaust port and cover the equilibrium port; and the probable leakage from want of perfection in the fit of the piston, which must move very freely in the cylinder, is often urged as an objection. It is considered by the writer however that there cannot be any such leakage with reasonably good work, because the grooves which are turned round the block piston will always be full of oil, and there is not time for this lubricant to be blown through from one groove to the next in any one stroke. Taking the average number of blows per minute to be 600, the full pressure is always on the front of the piston, and it is also on the back of it for at least three fourths of the whole time the machine is in action; therefore there is only one fourth of the time of one double stroke, during which the superior pressure on the front could have any tendency to blow the lubricant through the juncture between

the cylinder and the piston ; and when it is remembered that this time is only 1-40th part of a second, it will doubtless be admitted that there is not time for any loss or inconvenience to arise from this source. A few drops of oil supplied through the exhaust port into the cylinder for lubrication just before starting each hole are sufficient to keep the grooves of the piston filled with oil. This piston is found to be thoroughly satisfactory in working, and keeps in good order.

The method of fixing the tool in the holder is one of the minor details worth notice ; it was adopted to avoid observed inconveniences in the writer's experimental experience, and he believes it to be by far the best method in use. The plans of fixing the tool are very numerous, but many of them have been found in the writer's experience to be objectionable. All plans requiring the use of a hammer, or requiring a shoulder or a slot in the tool, or requiring more than one clamping nut to be turned, are attended with serious inconvenience; for a hammer in rough hands is a very destructive instrument to machinery, and slotted and solid collared bars of steel cannot be made in a mine smithy, and are unnecessarily expensive; besides which the writer has never yet found a cottered fixing that does not occasionally shake loose. But the method used in this machine is simple and convenient in action, and it never becomes loose in working. In making this clamp, the outer end of the holder is flattened for the seat of the nut, as shown in Figs. 1 and 2, Plate 18; the slot is then cut through it and fitted tightly with a piece of steel K forged of the required shape for the clamp, and the holder is then bored to receive the tool while the clamp is in place. The clamp K is then taken out, and its fitting eased a little, and its end screwed and fitted with a nut; on again returning it to its place, in consequence of the easing the hole in the clamp can be drawn tight against the tool, and this fixes it with the greatest ease and certainty. The shank of the tool is turned to fit the hole easily, and the end of it is spherical to fit the bottom of the hole, which receives the reaction of the blow in working.

Many ingenious means have been contrived and used from time to time for advancing drilling machines in their frames, as the hole

deepens; and great skill has been displayed in making the rate of advance self-acting and corresponding with the hardness of the rock. But all these contrivances necessarily complicate the machine, and increase the number of parts most likely to get out of order; and it is now generally admitted that the advantage, if any, of such arrangements is not an equivalent for the inconveniences they introduce: particularly as they do not save any working cost, because there must be a man in attendance on the machine, and he may as well turn the advancing screw by hand and bring his own judgment into action, as simply watch the machine and do nothing. For these reasons the drill now shown has no automatic advancing action. The objection may be made that the handle of the advancing screw can be turned too fast or too slow; but it is found that a very little practice enables the man to drive it exactly at the rate required for the stone he is working on. The machine itself is indeed the guide, for if the advance is too slow to keep pace with the drill, the piston calls attention by striking the front end of the cylinder; and if too fast, the machine stops in consequence of the exhaust being prevented, and will only start again by turning back the feeding screw. It is therefore almost impossible that a workman of ordinary intelligence should fail to learn this part of his duty by an hour's practice.

The means of fixing the machine for work in the end of a level has next to be noticed. The Stands which have been contrived for this purpose in connection with other drills are very numerous, and some of them very elaborate in their arrangements for placing the drill in all possible positions; but the most simple plan available for accomplishing the object is the best. What is needed is the means of rigidly fixing the drill in any required line, with the lightest plant that can be depended on for the time of drilling a hole. The Tubular Girder Stand designed by the writer for this purpose is shown in Fig. 6, Plate 19. It is composed of a wrought-iron tube M, about 3 inches outside diameter and about a foot shorter than the height of the level, fitted at each end with a long gunmetal nut N. A screw with a claw head which does not swivel is fitted into each of

these nuts, one of which is right-handed and the other left-handed. There is a sliding clamp P on the tube, which can be fixed in any position by turning the single hand-nut Q, Figs. 6 and 7, and is coupled by a pin to the head piece R of the drill frame. The end claws of the stand are set against hard wood planks on the floor and roof of the level, and are tightened by turning the body of the stand round, whereby it is fixed securely in its place; the drill is then coupled to the clamp P, and placed in the desired position, with its toes T against the rock, and these are tightened up and clamped. An oblique strut S, Fig. 8, is sometimes added behind the stand M, either above or below the clamp P, to render the stand more steady; but this is only requisite in large levels or shafts. The air hose U is then coupled on, and the machine is ready for action.

The advantages in working with this stand, over the other forms of post or girder stand that have been used, are that it is light enough to be moved and set up by one man, and does not require any locking nuts or clamps to the end pressure screws. Although these screws are not provided with clamps, it is impossible for them to be slackened or for the stand to slip from its place without first removing the drill; because unless the body of the stand is turned round, its length cannot be shortened, and so long as the drill is fixed, the stand cannot be turned, so that the two parts of the apparatus mutually lock each other. This stand has also an important advantage over the heavy carriages running on the tramway of the level, which are used with some drills. In those cases, after drilling a set of holes the stand is released from its fixings, and run back on the rails to a siding; the holes are then charged and fired, and all the rock blasted must be completely cleared away from the end, the floor made good, and the rails laid to the face, and the whole level cleared beyond the siding, before the great stand can be wheeled in to commence a new set of holes; this involves a great waste of time, causing a serious increase in the cost of driving a level. But with the stand now described, after drilling, charging, and firing one set of holes, as soon as a space of six or seven feet can be cleared by throwing the stuff back, the stand can be refixed, and a new set of holes drilled whilst the level is being cleared from the debris of the last blast.

Time is the great element of saving in driving a mine level, or making a cross-cut, or sinking a shaft; the cost per fathom may no doubt be greatly reduced by mechanical drilling, but this part of the saving is very small compared with the gain from saving of time that can be effected in sinking or driving works of exploration. Amongst the means available for saving time is the use of dynamite and the electric fuse. Dynamite tends to reduce cost in several ways; smaller holes may be used, and these can consequently be drilled faster and with less expenditure of steel and power. Dynamite breaks the rock up into smaller pieces, which can therefore be more readily removed. It also requires little or no tamping; the holes may be filled up with water or with loose sand, or the mouth of them stopped with a wad, and in either case the charge is fired with good effect.

The drilling apparatus that has been described is applicable to the usual run of work in metalliferous mines, for driving levels and sinking shafts of moderate dimensions. In Figs. 9 to 11, Plate 20, is shown another arrangement of this drill, mounted on a heavy moveable stand which has been designed by the writer for sinking shafts at the Southfield Colliery of the Nitshill and Lesmahagow Coal Co. in Scotland; and is intended to meet entirely different conditions from the machine previously described. In this case two large circular shafts have to be sunk through hard ground and near to each other, and there is powerful lifting machinery at the head of each shaft. The stand of the drill is made heavy enough that its weight may be sufficient for fixing it whilst working; it weighs about 15 cwts. A set of holes having been drilled in the bottom of the first shaft, the machine is at once hoisted out and lowered into the second shaft, there to drill a set of holes while the first set are being charged and fired and the stuff cleared away; the machine is then returned into the first shaft to repeat the process of drilling, so that it is constantly engaged.

The angular position of the slide-bed M of the drill, Fig. 11, Plate 20, is adjusted by the tangent screw S with swivel nut N and coupling; this screw is fitted with a clamp P, as are also each of the trunnions T, so that any position given to the slide-bed M is

retained with certainty until the drilling of the hole is finished. By these arrangements in the stand the introduction of long drills is facilitated. When the trunnion clamps T are released, and the top bearings RR of the swivel nut N thrown back, the nut and screw can be lifted and the inclination of the slide-bed M temporarily changed, while a longer drill is being introduced into the hole; this being done, the slide can be returned to its original place and the work resumed with certainty, because the nut of the tangent screw has never been unclamped at P, and therefore the angular position must be the same as before.

In the machines for Compressing the Air for working rock drills there is a great difference in principle and construction, and much complication exists in some that are in use, more particularly on the Continent; but the writer's experience is decidedly in favour of the most simple construction of pump, with the fewest parts that can be made to do the work advantageously.

The simplest plan is that in which the direct pressure of a column of water is employed for compressing the air; and a machine of this kind from the writer's design was used for the experiments with the rock drilling machine at Wheal Friendship copper mine, near Tavistock. The cylinder, alternately filled with air and water, was 18 inches diameter and 10 feet long, and received its water supply from the head in a large pump-column, and was fitted with automatic gear to reverse the water valves. When the water was at its lowest point and the cylinder full of air, the water discharge valve closed and the supply valve opened; the water then rose rapidly in the cylinder, and pressed the air before it into the reservoir through the air delivery valve at the top of the cylinder. When the surface of the water touched this valve, the water supply valve was closed and the discharge opened, and the water flowed away into the adit; the same process commenced over again as soon as the cylinder full of water was discharged. The objections to this plan are that it requires exceptional conditions, and the machine is large and heavy; the water required is equal in bulk to the atmospheric air to be compressed, and therefore it would be

inconvenient to use the machine below the free drainage level of a mine. But there are good points about the machine which make it worth attention wherever the requisite conditions are met with; for so long as there is water pressure in the supply column, and the pressure of air in the reservoir is less than that of the water, the machine will go on, and when the pressure of air is equal to that of the water it will stop, and it will start again directly this equilibrium is lost; so that no attendant is required, and no safety valve needed, the machine being its own governor and using only the exact quantity of water required for the expenditure of air that is going on.

The next plan of air compressor in use is a piston working in a horizontal cylinder which is open at both ends to water chambers, and the surface of the water rises and falls in these chambers, taking in and discharging alternately at each stroke a bulk of atmospheric air equal to the content of the stroke in the cylinder. This plan has the advantages of an entire freedom from clearance space for the compressed air to lodge in and expand again into the working air space of the next stroke; and also of the presence of a large body of water to keep the machine cool. But these advantages are in the writer's opinion outweighed by the disadvantages of increased first cost, increased bulk and weight, and the necessity of overcoming the inertia of a large body of water in reversing the direction of its motion at every stroke. Owing to this there is a necessity for working at a much lower speed, and consequently a larger machine is required to do a given amount of work.

Dry cylinders and pistons, taking and delivering air on both sides of the piston, are useful blowing machines, well suited for most purposes not requiring high pressures; but when the pressure is from 40 to 60 lbs. per square inch they are found to be defective. It is nearly impossible so to arrange the valves as to avoid considerable clearance spaces, whilst keeping them of sufficient capacity to admit of high rates of speed; the compressed air lodging in these spaces expands on the return of the piston, and fills a considerable portion of that space which ought to be filled with fresh atmospheric air. It is also found that the latent heat given out in the compression of the air greatly increases the temperature of the air taken in at each stroke, and consequently diminishes its quantity.

Another kind of pump is of similar construction, with the addition of provisions which partially overcome the above defects; the cylinder is water-jacketed, and a portion of water is injected at each stroke into the cylinder, cylinder caps, and air ways, for the purpose of keeping the parts cool and protecting the packing. A circulating pump is used for doing this, thereby necessitating a complicated arrangement of pipes and valves, which greatly increase the first cost, cause complication in the management, and render the apparatus liable to derangement.

In the arrangement of Air Compressing Pump shown in Figs. 12 to 16, Plate 21, the writer has endeavoured to carry out the idea that the most simple construction, with the fewest parts which can be made to do the work well, will be found best suited to meet the exigencies of adaptation to mining. A single-acting trunk plunger of gunmetal A is used, Fig. 15, working in a cylinder B, to which it is accurately fitted for its whole length; and at the open end of the cylinder there is a recess C fitted with a double cupped-leather, which is the only packing required. At the front end the cylinder is covered by an air chamber D; and the delivery valve E, which is a perforated plate covered with an india-rubber disc, is secured between the flanges of the cylinder and the air chamber; the inlet valve G in the front end of the trunk is of the same kind. In the back stroke the air passes through the trunk into the cylinder, and in the forward stroke the whole of it is delivered into the reservoir H, Fig. 13, because the two valves come nearly into contact. For the purpose of allowing the valves to come close together and thereby diminish the clearance space to the least possible, the guard plate of the inlet valve G in the trunk is made flat, as shown in Fig. 15, and slides forwards about 3-16ths inch on its centre pin when the valve opens at the commencement of the back stroke. The only clearance space is the holes in the delivery-valve grid, and even this is nearly filled by a sudden flush of water which is thrust against the valve at the moment the forward stroke is being completed. The water is introduced by the small valve J, Fig. 15, which is screwed into the flange of the air chamber D, and is closed directly the pressure of air in the cylinder exceeds that of the

column of water on the other side of the valve; but in the return stroke this valve opens and admits a regulated quantity of water in a jet striking against the upper part of the cylinder and flowing down its sides. This water supply also carries off the heat generated by the compression of the air; and it is useful in lubricating the india-rubber valves and keeping them free from oil.

This air compressor is driven by two belts, one on each side of the crank, as shown in Fig. 12, Plate 21, and it works well up to 120 revolutions per minute. The writer finds that there is power to spare for driving in this way at most mines in which rock drilling machinery is likely to be used; and there is some advantage in avoiding a combination of air pump and steam engine on the same bed, because the heat radiating from the engine is injurious to the performance of the pump, which should always take its air from the coldest and purest source available. The machine is varied however to suit any conditions, and may be driven by combined engines or turbines or ordinary water wheels, as may be most convenient in each case; it is made with a single cylinder on a cast-iron bed, or with a double cylinder either on a cast-iron bed or mounted on the air reservoir, as shown in Figs. 12 and 13; the latter is considered on the whole the most convenient arrangement.

In conclusion some of the advantages may be mentioned which are to be anticipated from a more general use of mechanical power in mining operations underground. Great things have already been done with it in large mining works, but far more will be done in its general application to smaller works, now that the machinery is brought down to reasonable dimensions. The bulk, weight, and cost of the plant have hitherto been insuperable objections to a wide application of it, but it is now brought within practicable limits. In effecting such a change in the mode of working, a series of unsuccessful experiments have to be passed through in the progress to perfection, and much prejudice of the practical workers has to be overcome. For many years the endeavour has however been persevered with to persuade the mining interest that it is advantageous to employ inanimate power in underground work,

and it is becoming generally admitted that so good a case has been made out as to demand attention and encouragement; a rapid development of the system may therefore be hoped for, as an aid to the working miner, relieving him from the evils consequent on hard work in ill-ventilated levels.

In visiting some of the Prussian mines for the purpose of seeing what progress had been made there in the practical application of this class of machinery, the writer had the opportunity of examining the practical working of the Sachs boring machine, which has been referred to previously, at a mine at Mechernich, 55 miles from Cologne. The day level of this mine is at the bottom of an immense quarry, all the walls of which are worked for lead; and the entrance to the workings was by a level of about 1000 feet length, and a ladder shaft at the end descending 120 feet to the level in which the boring machine was being used. After finishing one hole, the refixing and adjustment of the machine for boring another hole occupied 7 minutes. The tool first put in occupied 4 minutes in boring a hole 14 inches depth and $1\frac{1}{2}$ inch diameter; the cylinder was then drawn back in its frame, and another tool $1\frac{1}{4}$ inch diameter was put in the holder; this change occupied $5\frac{1}{2}$ minutes, and the hole was then made 12 inches deeper in $2\frac{1}{2}$ minutes. The final result was that a hole 26 inches deep was bored in hard sandstone in 19 minutes, including all the required changes and fixings; and from other holes this appeared to be about the average rate of work. The general result obtained in that mine is that a level 6 feet wide and 7 feet 7 inches high, or 45 superficial feet of end, is driven forward at the rate of 6 feet 5 inches in 24 hours by three men, using the machine and dynamite; and to do this, sixty holes are bored in ten sets, so that there are ten firings in 24 hours.

In reference to the relative cost of boring the above holes by hand, the time for one hole by one man (the system there used) is three hours, and to do that the drill required to be sharpened six times, while on the other hand the machine tool stands for two or three changes; so that the hand boring tool will sink $4\frac{1}{2}$ inches with one sharpening, but a machine tool will sink from

26 to 39 inches with one sharpening. This remarkable result, which is in agreement with the writer's own experience, is partly owing to the superior regularity of the machine in working, and partly to the fact that machine tools need not be sharpened to so acute an angle, and can be used when they are more worn than hand tools.

The wages cost of driving the level at Mechernich with the machine is 27 shillings in 24 hours; the men earn rather more money with the machine, and the work is better done. The level is perfectly ventilated, and the rate of driving is four times as great as with hand work, as shown by comparison with a corresponding case of hand labour in this country at Wheal Friendship. In this mine the end of a level of the same size was driven forward in one month 33 feet 6 inches by hand drilling and gunpowder, at a cost of £39 1*s.* 8*d.* At Mechernich with the machine work and dynamite the end is driven forward in the same number of days 154 feet, at a cost of £72 17*s.*, which is made up as follows :—

	£	*s.*	*d.*
Wages	32	8	0
Materials	25	9	0
Power and Repairs	15	0	0
Total	72	17	0

The comparison therefore is that the heading is advanced by hand drilling and gunpowder at the rate of £7 0*s.* 0*d.* per fathom, and by power drilling and dynamite at the rate of £2 16*s.* 9*d.* per fathom, showing a total saving of £4 3*s.* 3*d.* per fathom. This saving in cost is however but a small part of the advantage gained, because the power drilling gives the means of getting through four months' work in one month. Hence in driving an adit level an important tract of country may be unwatered in one fourth of the time it takes with hand labour; or in sinking a colliery shaft the coal may be reached in six months, instead of taking two years about it. In either of these cases not only is the whole cost of the establishment saved for three fourths of the time, but the profitable working can be commenced in one fourth of the time which it must occupy on the old system.

Mr. JORDAN exhibited a specimen of the rock drill described in the paper, which had been shown in operation to the members that morning in the neighbourhood, drilling holes in a block of granite, and worked by steam instead of compressed air.

Mr. JOHN TAYLOR regretted that his brother, Mr. Richard Taylor, who had had an opportunity of seeing the Sachs rock drill tried at Wheal Friendship copper mine near Tavistock, was not able to be present. The members who had seen Darlington's drill at work that morning would be struck especially with its simplicity and portability, which to himself appeared a great recommendation. The whole machine could be carried by two men, one carrying the cylinder, and the other the upright shaft forming the stand, by which the drill could be fixed in any mine-level and at any angle. In most metalliferous mines the power to work the drill would be supplied by compressed air conveyed down the shaft and along the levels in the wrought-iron tubes ordinarily employed for that purpose, with a short length of india-rubber tubing at the end; and there was apparently no practical difficulty in fixing and working the drill. This machine certainly possessed remarkable advantages in its great simplicity and lightness, the small number of its parts, the apparent ease with which they could be kept in repair, the facility for changing the drills, and the great variety of speeds that could be attained in working. He had seen the drill working at the rate of very nearly 1000 blows a minute, and down to 300 or 400; but he was rather of opinion that no very high speed would be desirable, and that there was risk of the perfection and durability of the machine being impaired by endeavouring to obtain a very high speed with the object of getting through a large quantity of work in a very short time. The mode in which the turning of the tool was effected by self-acting means, by the rifled bar working within the piston, appeared to him a highly ingenious arrangement possessing great merit, though he did not know that it was peculiar to this machine. Another feature was the entire absence of valves of any kind, which gave this machine a great advantage over others that had been invented. He had sent some of these drills to the Cape and to

several other places where he was anxious to introduce some tool of this kind; and the difficulty at present was to get the machines supplied as rapidly as they were wanted. Without wishing to express a preference for this particular drill over others, he could say that miners generally were desirous of having some machine of this kind, in order to remove some of the difficulties that existed at the present time in regard to labour.

With respect to dynamite, to the employment of which reference had been made in the paper, he had had a considerable experience of its use in some mines, especially in Portugal, and had derived great advantage from it. The peculiar effect of dynamite seemed to be that the force of the explosion was expended downwards, and after the shot had been fired the rock was so thoroughly shattered that the miner could go to work at once with his pick; and a larger quantity of rock was loosened by the explosion than he had ever found to be the case with an equal quantity of any other explosive substance that he had used. The employment of dynamite and the application of the improved drilling machine now described would he believed not only enable the cost of opening mines to be cheapened, but also, what was of more importance, would enable them to be opened more rapidly; for at the present time this work could not be got on with fast enough.

Mr. J. Lee Thomas said he had been much pleased to see this rock-drilling machine, which appeared to him to be very simple; and simplicity was the great object in machines for that purpose. Anything which tended to quicken operations in mining must of course be of very great advantage. This appeared to be a very pliable machine, and adapted to boring holes in any direction, which was one of the essentials in machines of that kind, in order that they might be enabled to take advantage of any jointings in the rock.

Sir John Coode considered perfection of the rotating arrangement for the tool was a matter of very great importance in rock-drilling machines; and having had occasion to use two other kinds of rock drills, he had not been quite satisfied with

either of them in that respect. The rock in which he had had to employ them was very hard syenite, and it was found necessary for the greater part of the holes to be bored in a nearly horizontal direction; great difficulty had been experienced in working the machines satisfactorily, owing to the want of perfection in the rotating arrangement, and the result had been in a great many cases that the hole had become polygonal after drilling to a certain depth, and the machine had then been obliged to stop in consequence of the drill getting jammed in the hole. This difficulty he believed arose mainly from the fact of the holes being horizontal, in consequence of which the forward end of the drill drooped and the edge of the drill bore upon the lower side of the hole, and an amount of resistance to the turning of the drill was thus occasioned for which provision had not been made in the rotating arrangement of the machine. The objection had to some extent been got over by altering the form of the drill; but all the rock-drilling machines that he had hitherto seen had certainly been defective as regarded the rotating arrangement. In that respect at any rate he considered the machine now described would prove completely successful in accomplishing the object in view. The simple construction of stand for carrying the drill seemed a very good one, and was evidently very applicable to mining purposes, such as sinking shafts and driving drifts, but perhaps not so suitable for quarrying operations. He was favourably impressed with the machine, and hoped soon to have an opportunity of trying it.

Mr. JORDAN remarked that the means for rotating the drill in the machine shown was unusually simple and proved very satisfactory in working; the spiral bar upon which the piston slided was prevented from turning when the piston came in, by the ratchet head of the bar being held by detents, and the piston with the tool was consequently turned round about 1-15th of a revolution during the return stroke; but in the forward stroke, the inertia of the piston being so great in comparison with the slight friction of the detents upon the ratchet in turning forwards, the piston made its stroke without turning, and caused the spiral bar to turn within it. Thus the drill struck a straight blow without

turning, and was rotated whilst coming back, ready for the next stroke. The only parts found to require renewal in working were the two small spiral springs, and either of these could be readily replaced by simply taking out the screw plug, without interfering with any other part of the machine; but they were found to last a long time, as their pressure was very light.

Mr. P. G. B. Westmacott mentioned that the first experience he had had in regard to rock-drilling machines had been with that of Capt. Penrice, in which the great difficulty had been, in addition to the breaking of the edge of the tool, the abrasion of the tool at the sides, in consequence of the hole getting continually narrower and narrower as the depth increased. Having subsequently had occasion himself to design a special drill to be worked by hydraulic pressure, it had occurred to him that, in order to prevent the edge of the tool from breaking and also to prevent the wear against the sides of the hole, the right principle of striking the blow might probably be to imitate the action of the mason, by holding the tool against the face of the rock and then striking the blow upon the head of the tool. That action was accordingly tried, and was found to succeed very well, so much so that he had known a drill make as many as twenty holes of about 16 or 18 inches depth in hard limestone without requiring to be re-sharpened, the rate of driving the holes being from 2 to 3 inches per minute. That machine was an experimental one, and did not continue at work very long. He had not had since then the time or the opportunity for doing anything further in the matter; but he was satisfied that the plan of holding the tool firmly with pressure against the rock before striking the blow, and then striking the blow upon the tool itself, was the correct way for maintaining a parallel hole and preventing the tool from getting worn at the side.

Mr. R. H. Tweddell suggested that, if, as he understood it to be stated, the presence of a steam engine in the neighbourhood of the air-compressing pump described in the paper affected its efficiency, this type of machine would hardly be applicable to deep mining, when the temperature was very high.

The PRESIDENT observed he understood the writer of the paper to say it was not merely in the case of the particular air compressor described in the paper that it would be inconvenient to have a steam engine close by; but that it was undesirable with any compressor, because the very close propinquity of an engine would heat the air taken in by the pump, which ought, for realising the greatest effect, to be received as cold as possible.

Mr. E. J. C. WELCH observed, with regard to the grooves round the piston of the drill for rendering it air-tight in working, he had recently constructed a steam engine having the gland in the cylinder cover constructed with grooves on the same principle; and he had found that as long as the grooves in the gland were kept clear of oil the gland was steam-tight, but when any oil got into them it soon clogged them up, and the steam then blew through. It was true that while the grooves continued clear of oil there was a slight puff of steam through the gland at the commencement of each instroke; but this ceased as soon as the piston-rod had got into motion. In consequence of the leakage that took place when the grooves became clogged with the oil that was used for lubrication, he had been obliged to abandon the plan, and to bore the gland out and pack it in the ordinary way.

Mr. JORDAN gave the particulars of the holes bored by the drilling machine which had been shown at work to the members that morning, driven by steam and drilling holes of $1\frac{1}{4}$ inch diameter in a good sound block of hard grey granite:—

No.	1	hole,	$11\frac{1}{2}$	inches	depth in	1	min.	30	secs., or	7·67 inches per minute.
„	2	„	12	„		1	„	35	„	7·58 „
„	3	„	12	„		1	„	45	„	6·86 „
„	4	„	12	„		2	„	45	„	4·36 „
„	5	„	12	„		2	„	45	„	4·36 „
„	6	„	12	„		2	„	20	„	5·14 „
„	7	„	$12\frac{1}{2}$	„		2	„	30	„	5·00 „
	Total		84	„		15	„	10	„	5·54 average rate.

The aggregate depth bored was thus seen to be 84 inches at an average rate of $5\frac{1}{2}$ inches per minute, the rate ranging from about $4\frac{1}{2}$ to

$7\frac{1}{2}$ inches per minute; the variation was probably due to differences in the pressure of steam and in the condition of the tool edge, but he thought miners would consider any of these borings were done fast enough to meet all the requirements of mining operations. In the fifth hole the reduction of speed was due to the breakage of the tool, which on being taken out of the hole was found to have had its cutting edge completely broken off, the fracture having occurred at the time of starting the hole. The steam was admitted to the machine through a half inch cock, which was more or less closed in each experiment for the purpose of varying the number of blows per minute.

In the Sachs drilling machine, which was much in use and which he had seen in operation at Mechernich, the number of separate parts was shown by the drawing exhibited (Plate 22); these machines were very beautifully made and did their work admirably, and with one of them a very large level had been driven forwards at the rate of as much as 6 feet in 24 hours. It was however a kind of machine, the details of which were in his opinion too delicate for the work that it had to perform. The piston having two rods forged solid with it required a gland at each end of the cylinder, Fig. 17. The tool was fixed in the end of the piston-rod by a cotter, which was jammed against the top of the slot hole in the tool by means of the locking nut screwed upon the extremity of the piston-rod, Figs. 17 and 20. So long as this nut remained fast on the screw, the tool was well fixed; but the actual result which he had found in practice was that the violent concussion of the tool in striking against the bottom of the hole in the rock frequently shook the nut loose, and there was great difficulty in keeping it tight; directly it got loose, the machine could go on no longer, but had to be stopped and the nut tightened up again before any more work could be done, and this was therefore one of the points that he thought called for improvement.

The cylinder of the machine had the ends slightly chambered out for facilitating the admission of the compressed air, Fig. 17. The piston and the gland at the front end of the cylinder were both kept air-tight by turned grooves, the same as in the drill described in the

paper; and there was no packing in any part of the machine. The piston-rod being larger in the centre than at the ends could not be passed through the gland at either end of the cylinder; and this difficulty had been very cleverly overcome by making both the glands in halves. In preparing the glands, the halves were first of all planed truly down to the centre line, and being then soldered together with a very thin tin joint, the whole was turned and bored and finished like a solid casting; after which on being warmed the halves fell apart again. The fitting was so nicely done, that, when the whole was put together on the piston-rod, the joints kept very nearly air-tight, though the glands were without any packing. The slide-valve was very carefully got up, and worked between two parallel faces; the compressed air was admitted underneath the valve, through the centre port, and the exhaust was at each end. The pressure was admitted to the back of the valve through a small hole in its centre, and the valve was fitted with an annular back-plate or distance-piece, resting on a leather washer which had sufficient elasticity to keep both the valve and the back-plate in contact with the surfaces they worked against, so that neither of them was held against the face by the air pressure, but only by the slight elastic pressure of the washer.

The number of separate parts requisite to work the valve, and the number of separate parts requisite to turn the drill, constituted a serious objection to the Sachs machine, and rendered it practically unsuited for mining operations; from the number of pieces, the advantage of getting rid of so great a number of parts would at once be seen. With the improved drill described in the paper the same work was done without requiring more than the very few parts shown in the drawing (Plate 18). The cylinder and front gland were one casting, and when the cover was bolted on, the whole formed practically a single piece; and the only other piece was the piston and rod, which were cast in one. These two pieces, one fixed and the other moving, were really the only two pieces requisite for the reciprocating action of this machine. The difficulty of keeping the gearing in order, which had always been the greatest difficulty in rock-drilling machinery, was thus overcome by getting rid of

gearing altogether; and this he thought was a great practical improvement.

The PRESIDENT said there could be no question that the subject of the paper—the employment of machines in rock boring—was an extremely important one; for it must he thought be admitted that it would be difficult to over-estimate the value of appliances that would increase the rate at which mining work and other work in hard rock could be carried forward; and this was true, whether the increased expenditure were attended by any saving in the mere cost of labour or not. But from what had been seen of the working of the drill as shown in operation that morning, he thought that with a machine so simple as this, reduced to only two elementary pieces, there was every reason to anticipate a great saving in cost of working. It was very interesting to notice the advance that had been made in this kind of machine during the course of the last ten years. In a description given in 1864 of the progress of the Mont Cenis tunnel,* it was stated that for every drilling machine at work in the tunnel there were four in the shop under repair; and it was roughly estimated that with the machines there used the work might be pushed forwards three times as fast as by hand labour, but the cost would be two and a half times as much. The great advantage of getting the work done quickly in such an undertaking as that was then pointed out; and it was shown that, even if done at two and a half times the cost, it was well worth while to pay it to attain the speedy completion of the work. When therefore a machine was brought forwards, by which there was every probability not only of greatly increasing the rate of progress but also of doing the work at a diminished cost, as it appeared had already been done even by the Sachs machine, he was sure such a machine as that forming the subject of the paper must be a matter of great interest to all engineers; and he was also sure that all present would join in the hope that those who had devoted so many years to perfecting the machine there described would be rewarded with the success deserved by so meritorious a contrivance.

* Proceedings Institution of Civil Engineers 1863-64 vol. xxiii page 258.

He proposed a vote of thanks for the paper to Mr. Jordan and also to Mr. Richard Taylor, which was passed.

The Meeting then terminated.

Fig. 1. *General Plan of Railways communicating with the Port of Cardiff.*

COLLIERIES

A *Glamorgan Co*
B *Powell's Duffryn*
C *Nixon's*
D *Merthyr Vale*
E *Castle Pit*
F *Harris'*

M *Merthyr Sewage Farm*

IRONWORKS

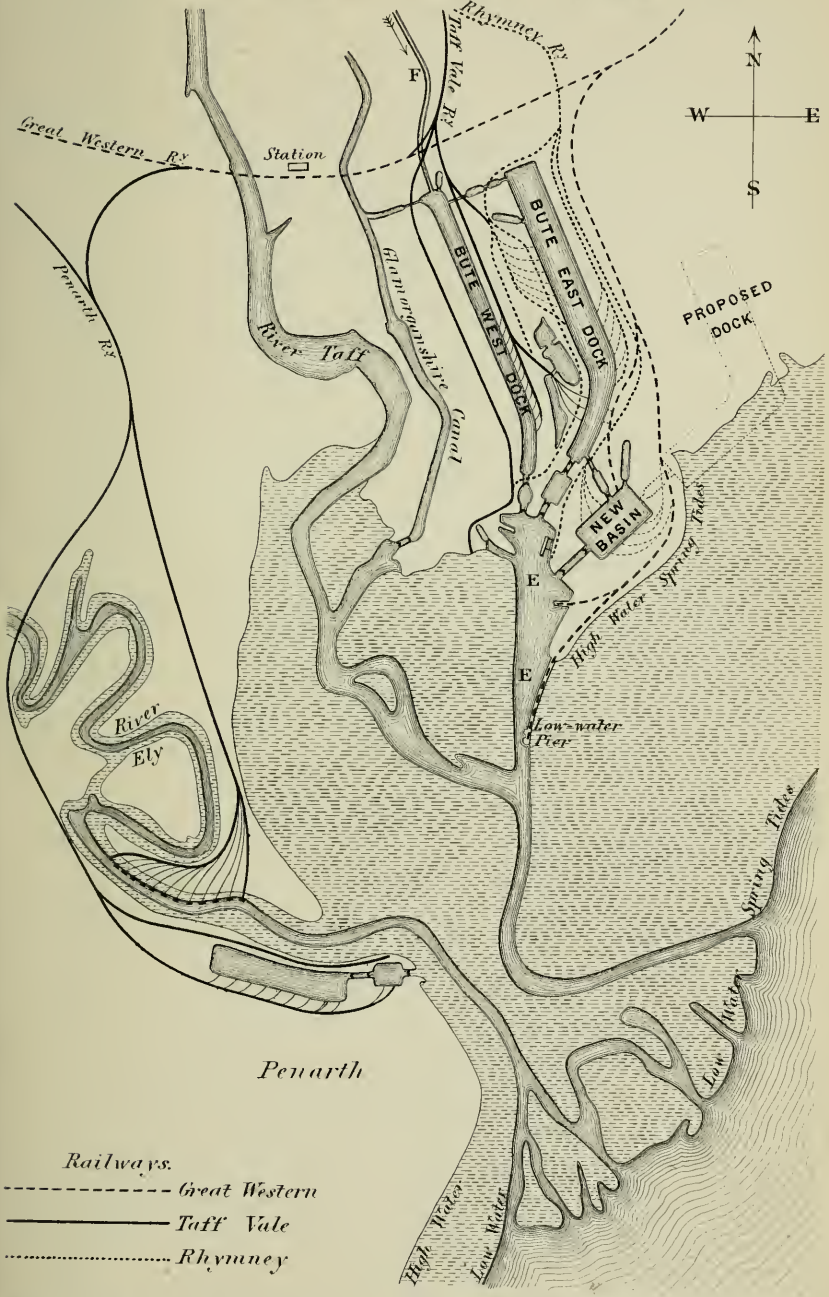
1 *Cyfarthfa*
2 *Plymouth*
3 *Dowlais*
4 *Rhymney*
5 *Tredegar*
6 *Ebbw Vale*
7 *Blaina*
8 *Nantyglo*
9 *Blaenavon*

(*Proceedings Inst. M.E. 1874*)

Scale 8 miles per inch.

10 5 0 10 20 Miles.

Fig. 2. *General Plan of Cardiff Port and Docks.*

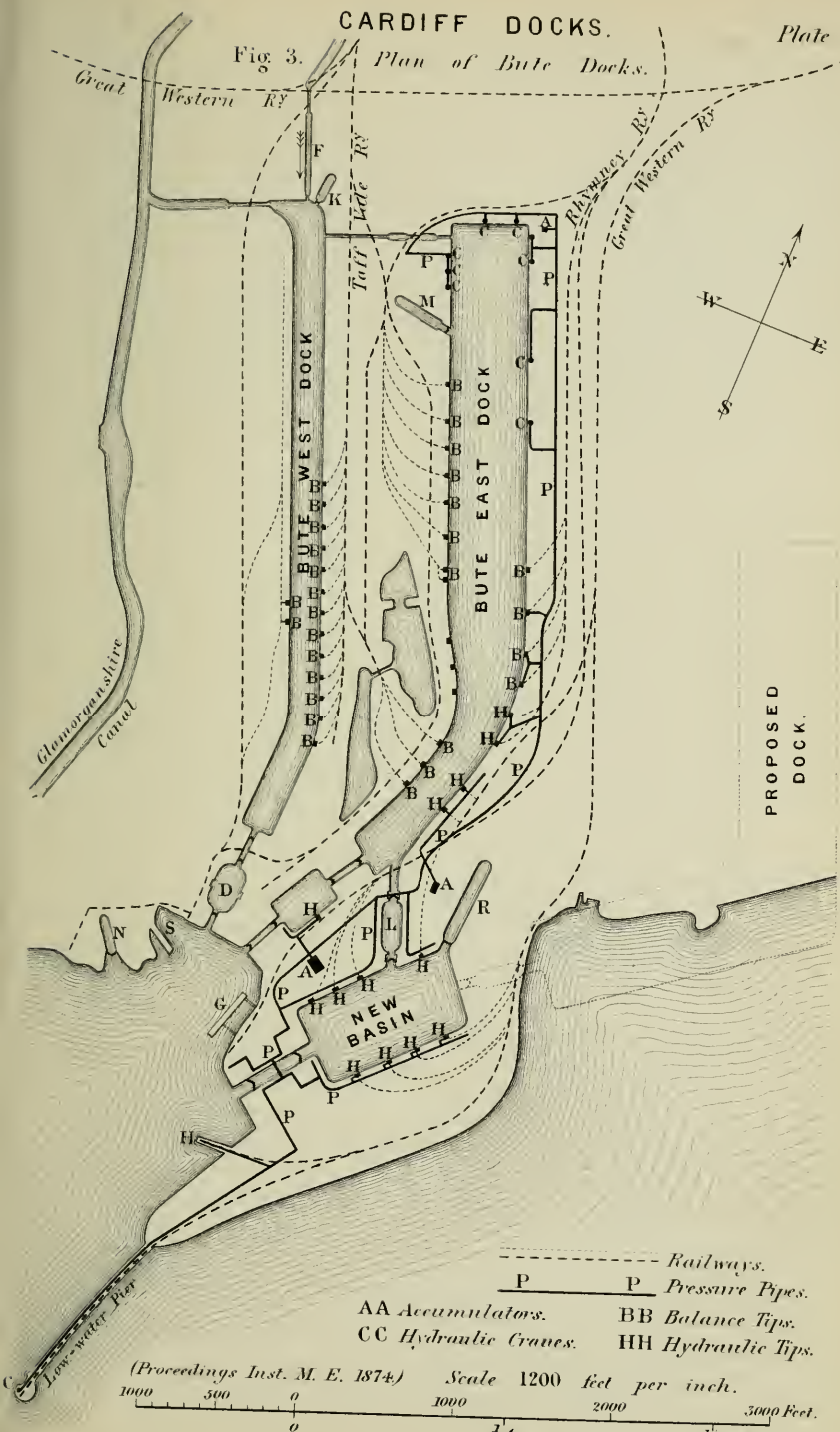


(Proceedings Inst. M.E. 1874.)

CARDIFF DOCKS.

Plate 25.

Fig. 3. *Plan of Bute Docks.*



80 *feet Entrance Lock and Gates to New Basin.*

Fig. 4. *Transverse Section at* XX.

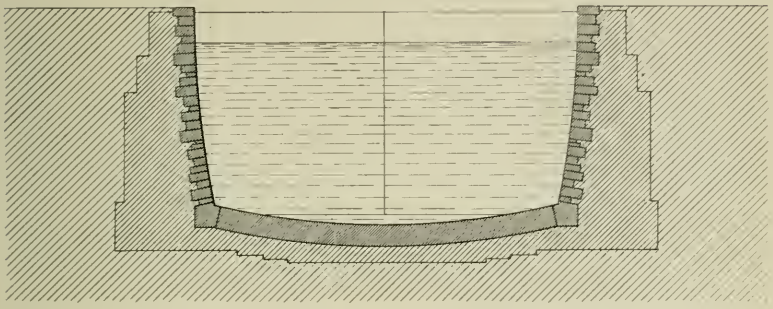
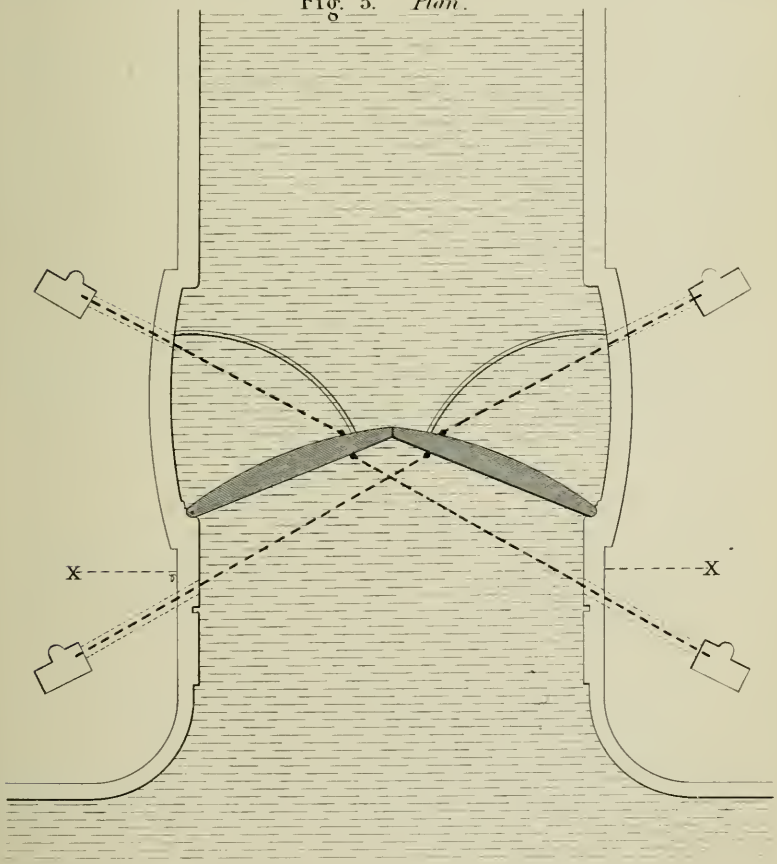


Fig. 5. *Plan.*



(Proceedings Inst. M. E. 1874.)

Scale $\frac{1}{480}$ *th*

0 10 20 30 40 50 60 70 80 90 100 *Feet*

CARDIFF DOCKS.

Dock Gates of 80 feet Entrance Lock.

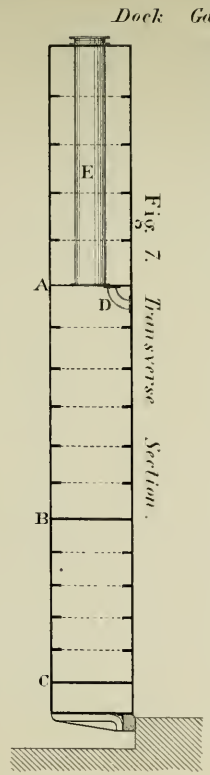


Fig. 7. *Transverse Section.*

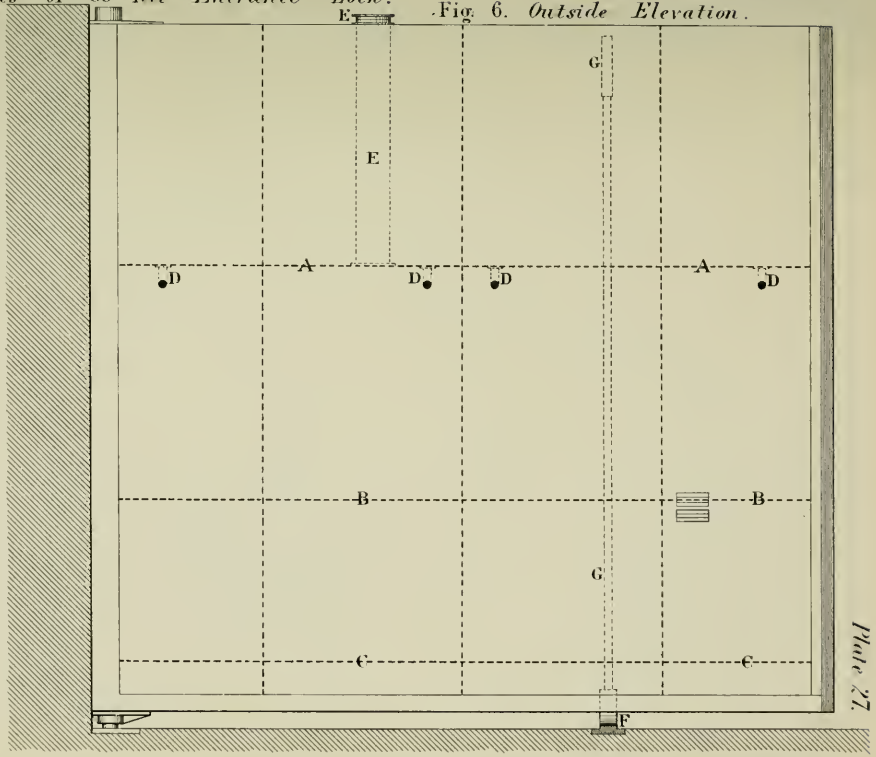


Fig. 6. *Outside Elevation.*

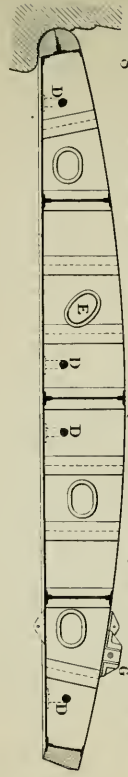


Fig. 8. *Sectional Plan showing Water-tight Diaphragm.*

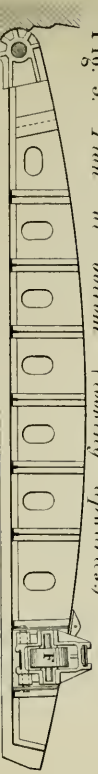


Fig. 9. *Plan at bottom (looking upwards.)*

Scale 1/140 th. 10 5 0 10 20 30 40 Feet.

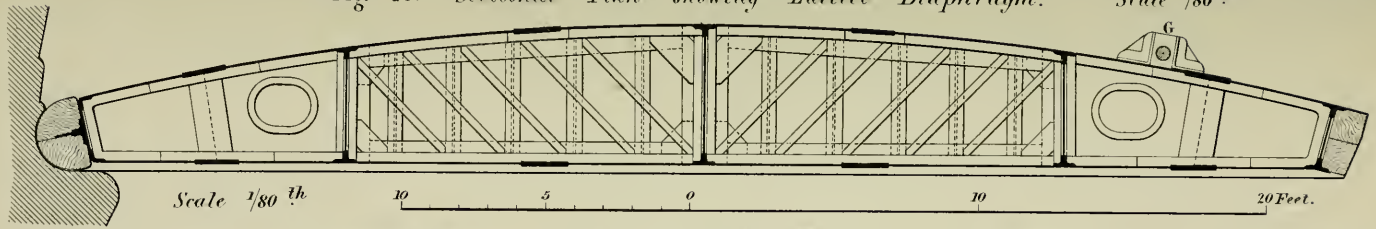
Plate 27.

(Proceedings Inst. M. E. 1874.)

CARDIFF DOCKS.

Dock Gates of 80 feet Entrance Lock.

Fig. 10. *Sectional Plan showing Lattice Diaphragm.* *Scale 1/80 th*

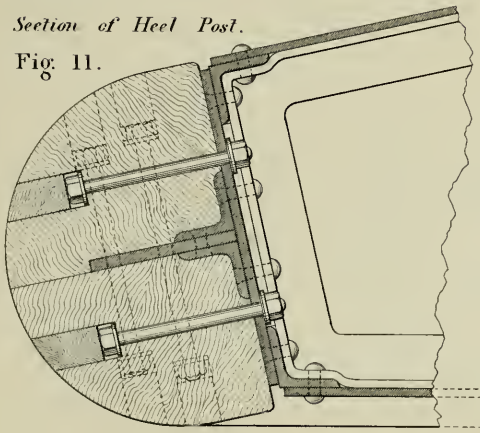


Details of Timber Work.

Scale 1/16 th

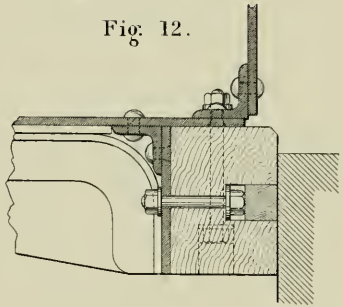
Section of Heel Post.

Fig. 11.



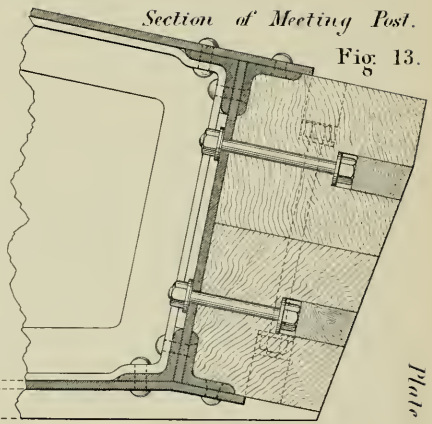
Section of Sill.

Fig. 12.



Section of Meeting Post.

Fig. 13.



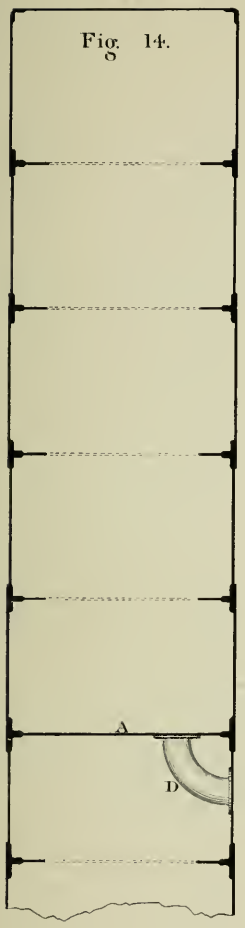
Scale 1/16 th 10 5 0 10 20 Inches.

(Proceedings Inst. M. E. 1874.)

Dock Gates for 80 feet Entrance Lock.

Transverse Sections.

Fig. 14.



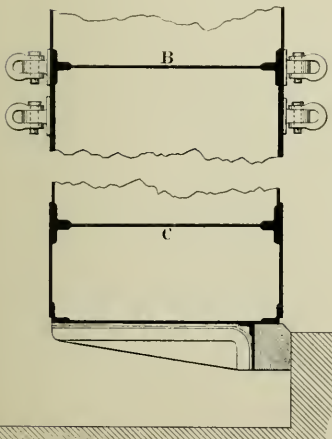


Fig. 15.

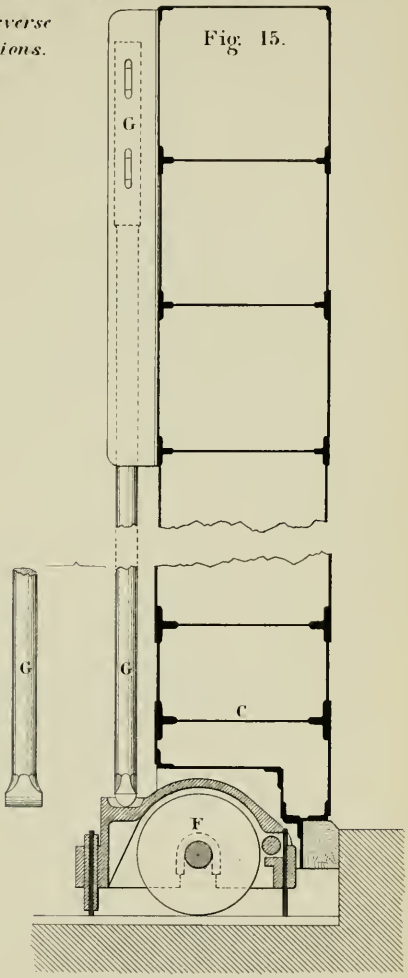
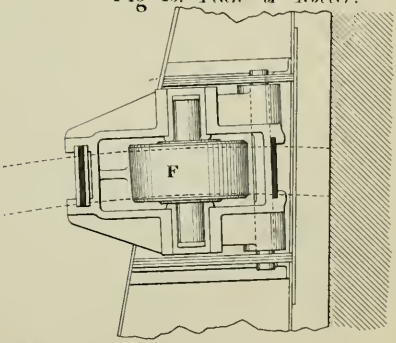


Fig 16. *Plan of Roller.*



(Proceedings Inst. M.E. 1874)

Scale 1/50 0 1 2 3 4 5 *Feet.*

Dock Gates of 80 feet Entrance Lock.

Anchor Plate.

Fig. 17. *Plan.*

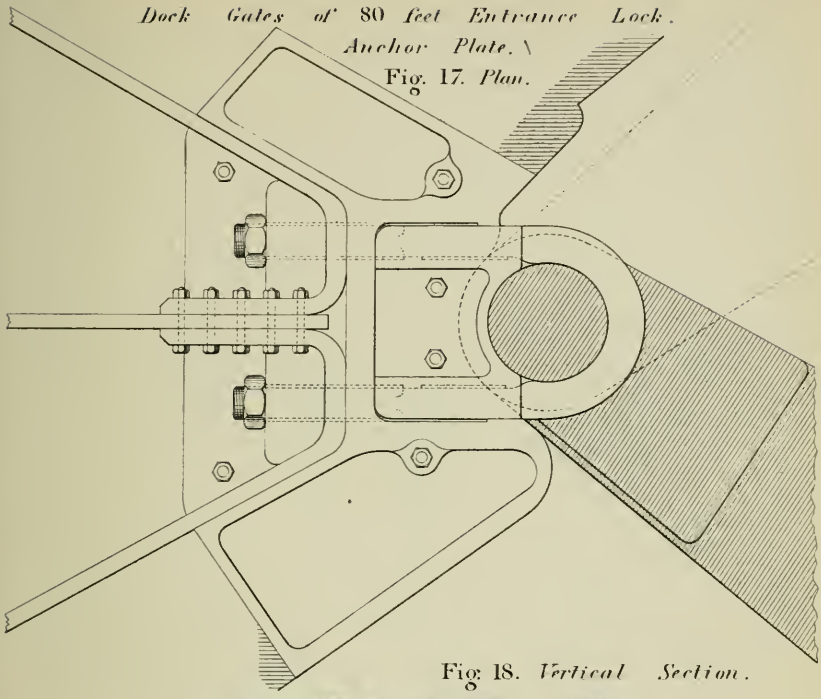
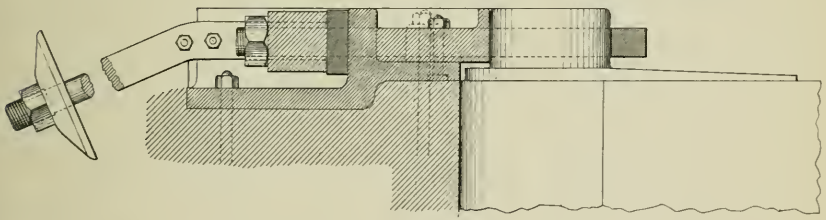


Fig. 18. *Vertical Section.*



Bottom Pivot.

Fig. 19.

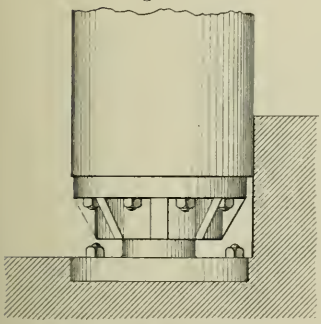
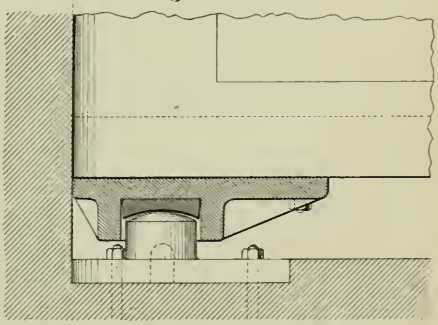


Fig. 20.



(Proceedings Inst. M. E. 1874.)

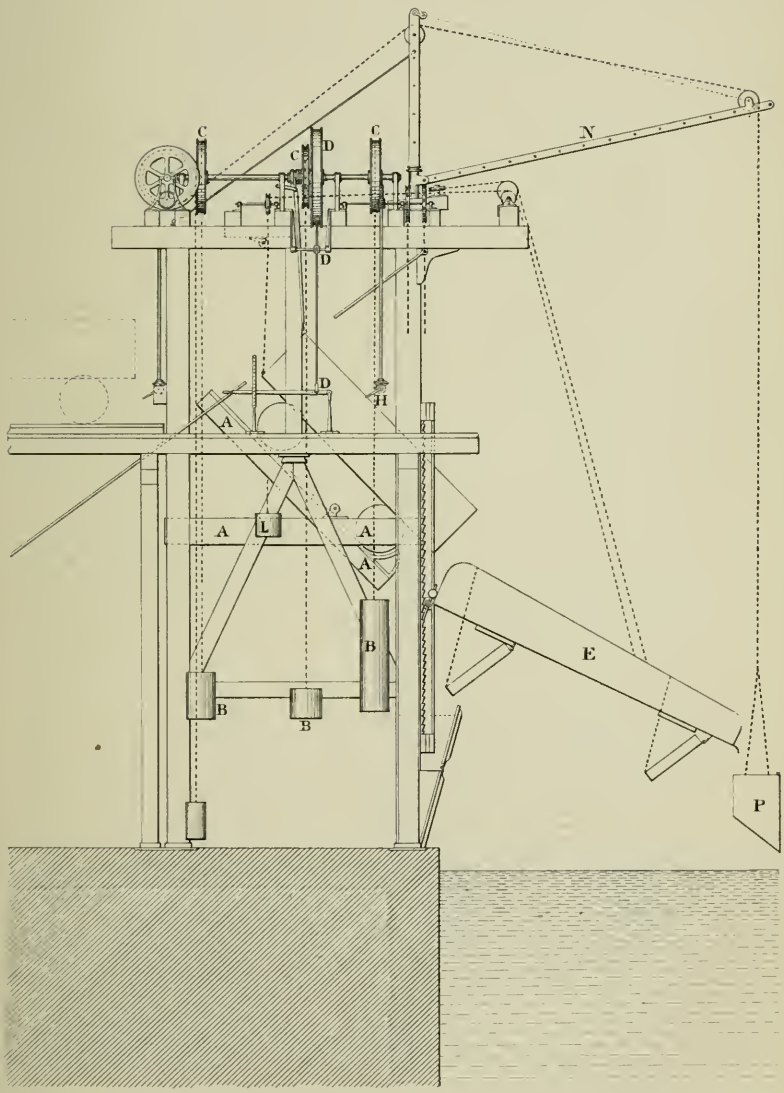
Scale $\frac{1}{30}$ *th*

0 1 2 3 4 5 6 Feet.

Balance Tip.

Old mode of tipping, by lowering the cradle.

Fig. 21. *Side Elevation.*



(Proceedings Inst. M. E. 1874.)

Scale 1/140 *th*

10 5 0 10 20 30 Feet.

CARDIFF DOCKS.

Plate 32.

Balance Tip.

Improved mode of tipping, by raising the end of wagon.

Fig. 22.

Side Elevation.

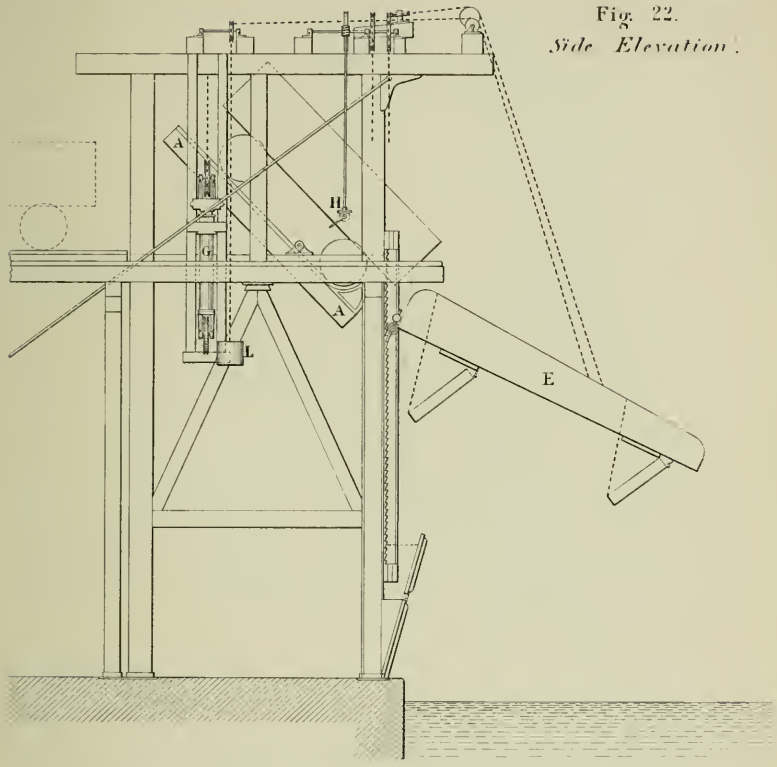
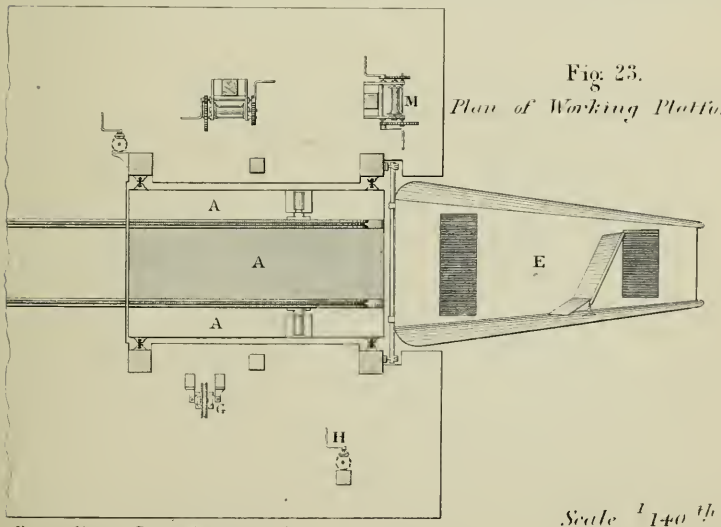


Fig. 23.

Plan of Working Platform.



Scale $\frac{1}{140}$ *th*

10 5 0 10 20 30 Feet.

Balance Tip.

Fig. 24. *Front Elevation.*

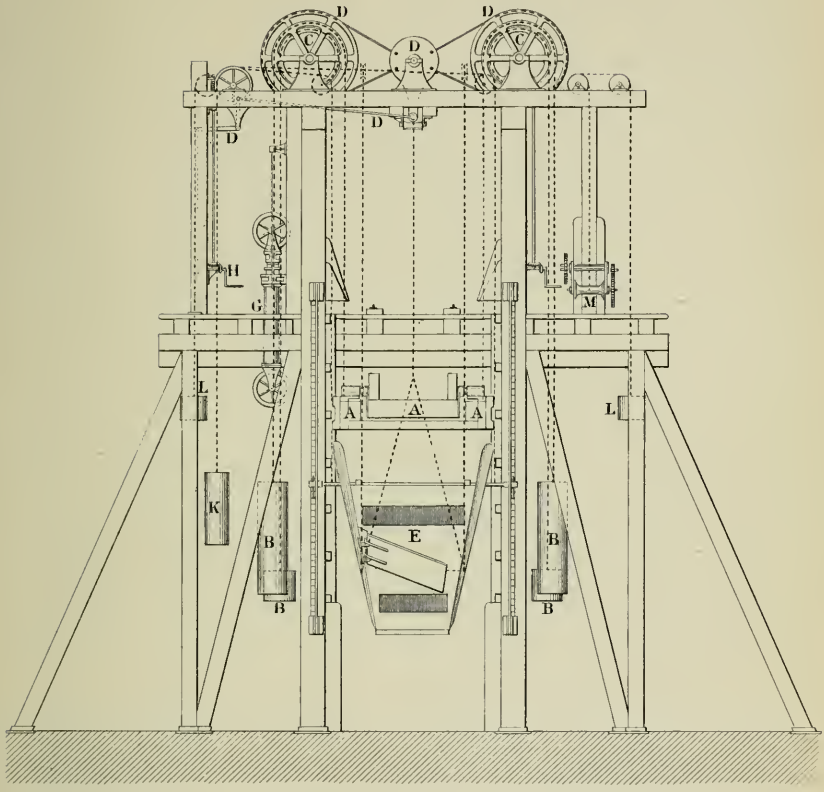
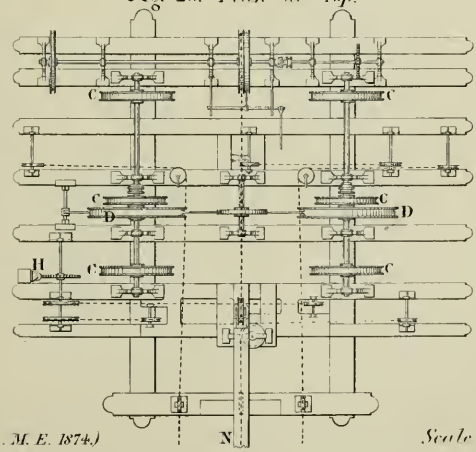


Fig. 25. *Plan at Top.*

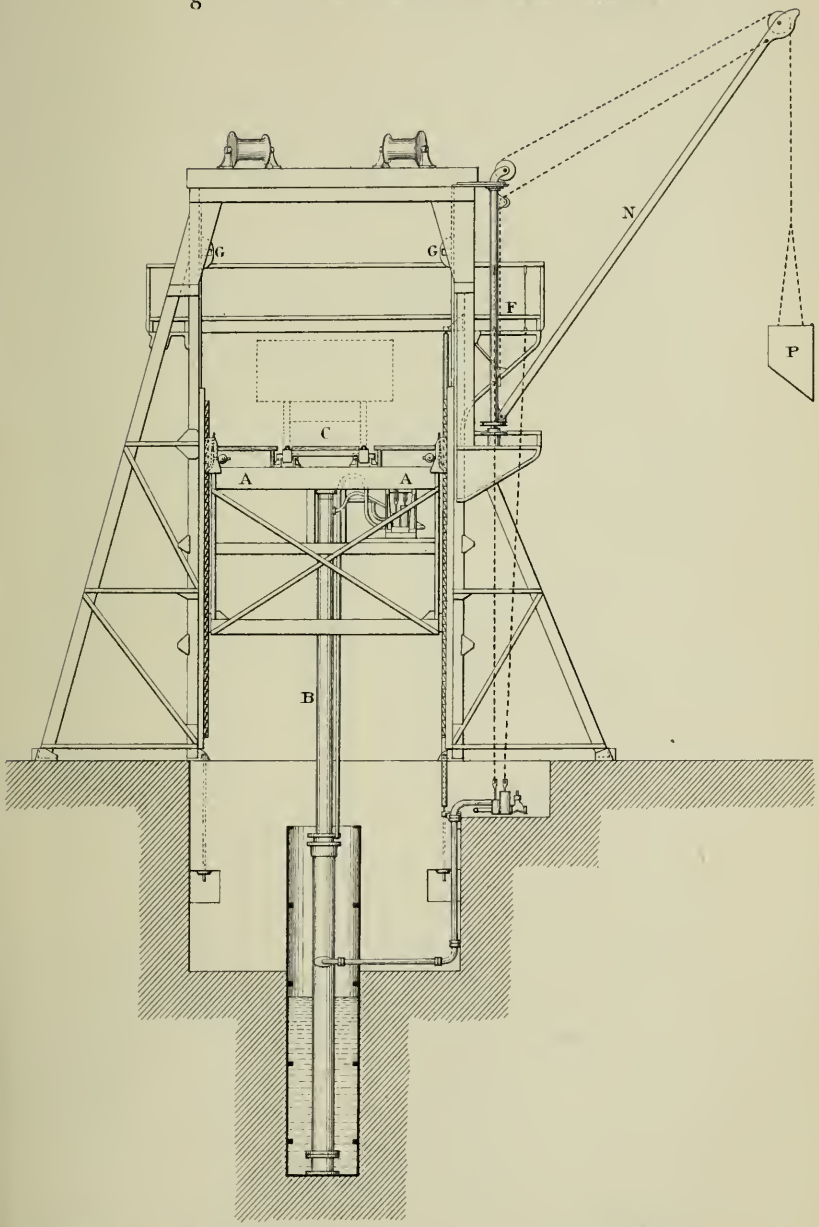


(Proceedings Inst. M. E. 1874.) *Scale 1/40 th*

10 5 0 10 20 30 Feet.

Hydraulic Tip.

Fig. 26. *Front Elevation and Section.*



(Proceedings Inst. M. E. 1874.)

Scale 1/140th

10 5 0 10 20 30 Feet.

CARDIFF DOCKS.

Hydraulic Tip.

Fig. 27. *Longitudinal Section.*

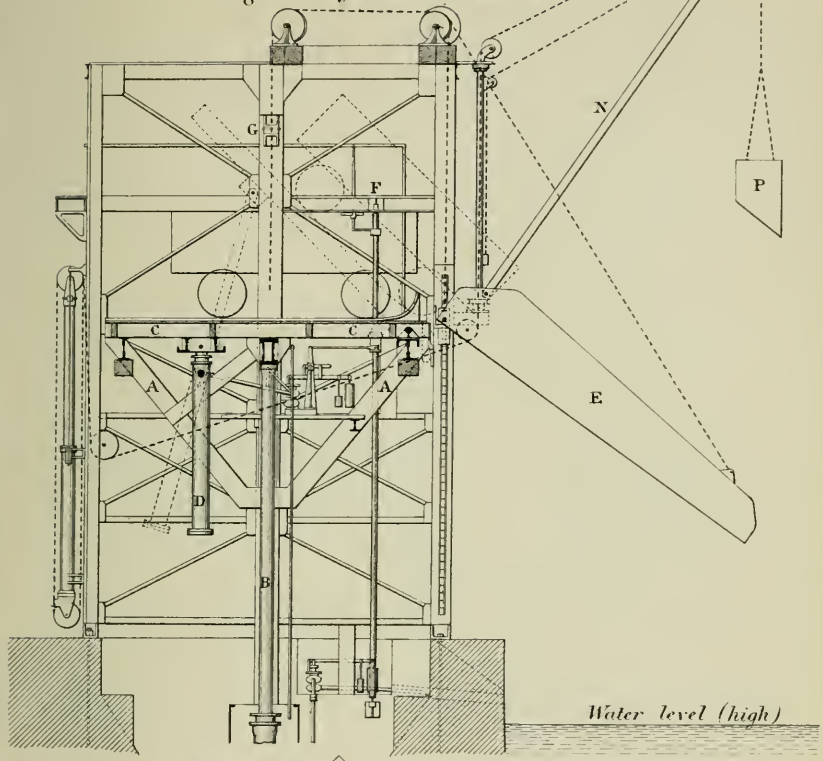
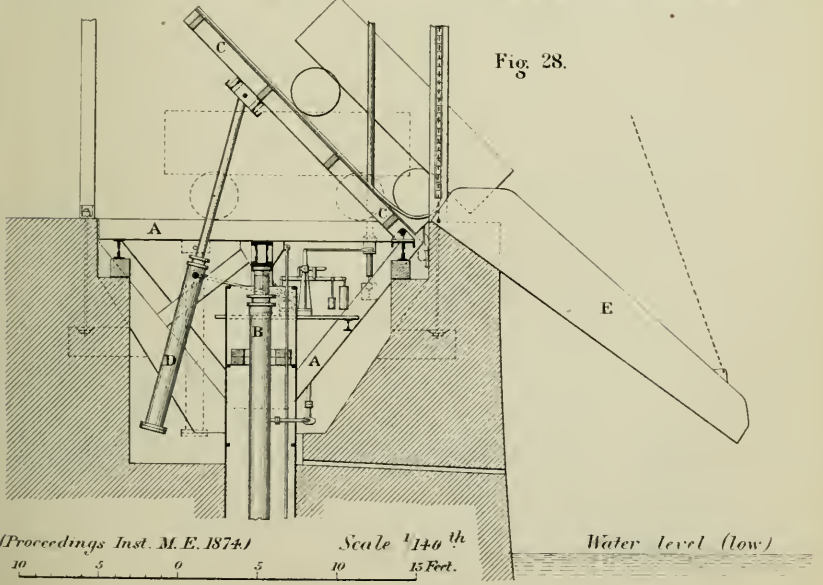
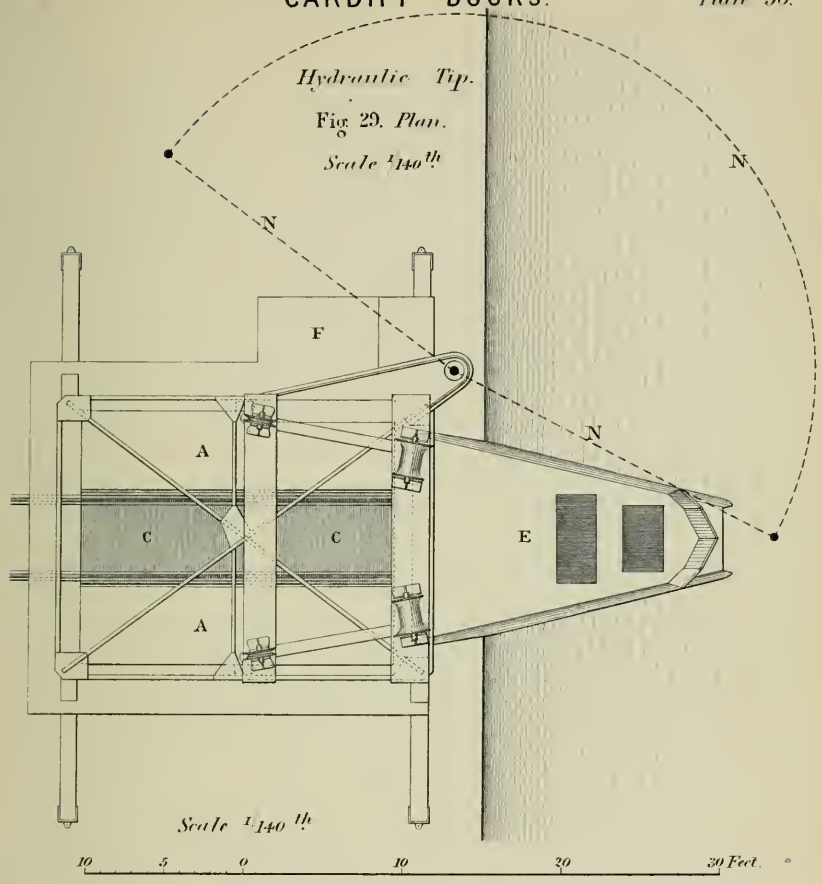


Fig. 28.



(Proceedings Inst. M.E. 1874) *Scale 1/40 th*

10 5 0 5 10 15 Feet.



Shipping Coal.

Fig. 30.

Highest Water Level.

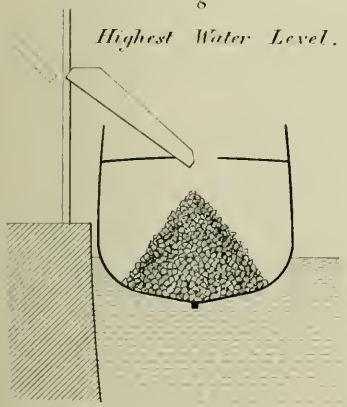
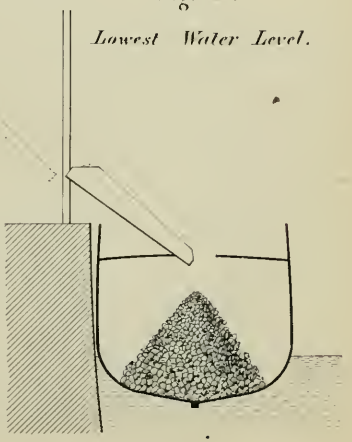


Fig. 31.

Lowest Water Level.



(Proceedings Inst. M. E. 1874) Scale 1/360th

10 0 10 20 30 40 50 Feet.

Hydraulic Hauling Engine.

Fig. 32. *Transverse Section.*

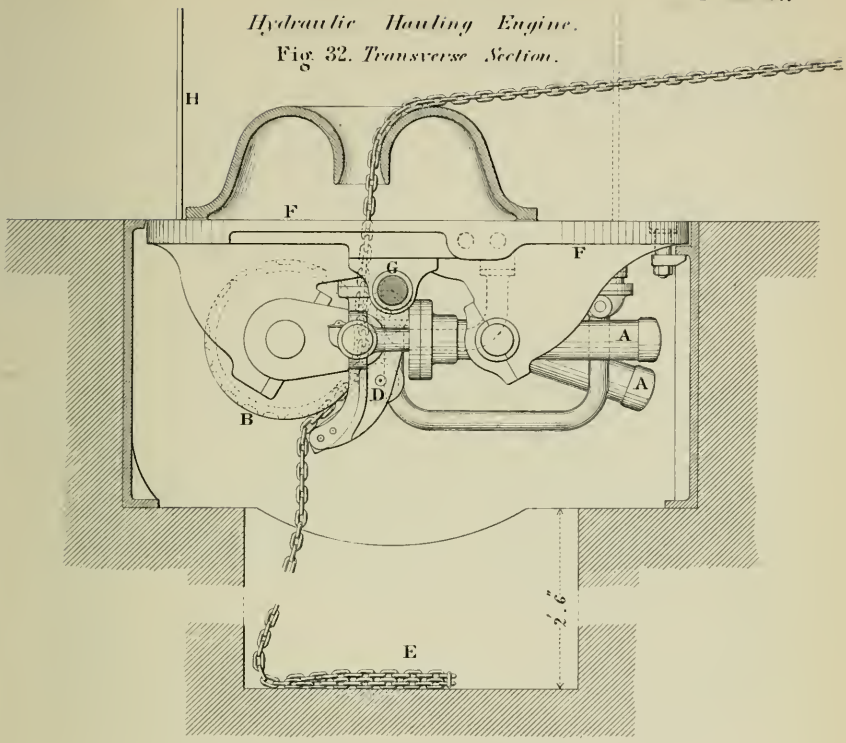
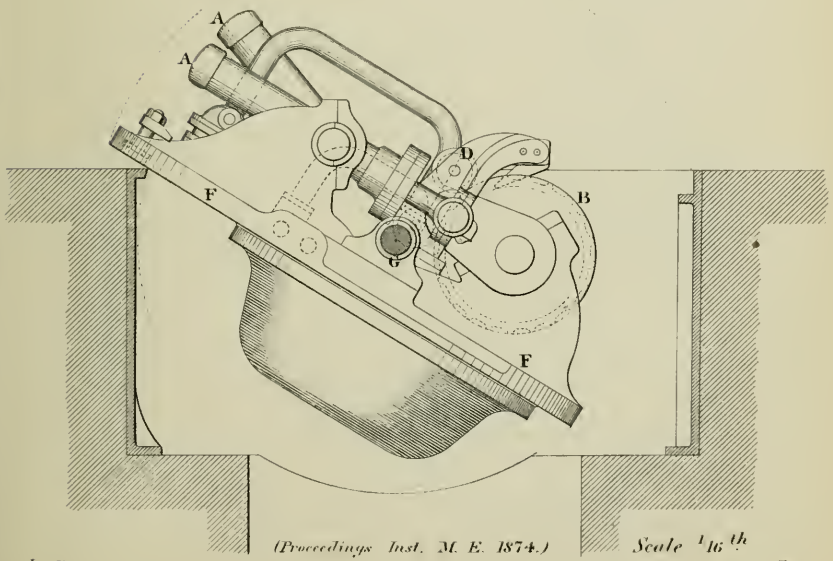


Fig. 33.



(*Proceedings Inst. M. E. 1874.*) *Scale* 1/16th

Ins. 12 6 0 1 2 3 Feet.

Hydraulic Hauling Engine.

Fig. 34. *Elevation.*

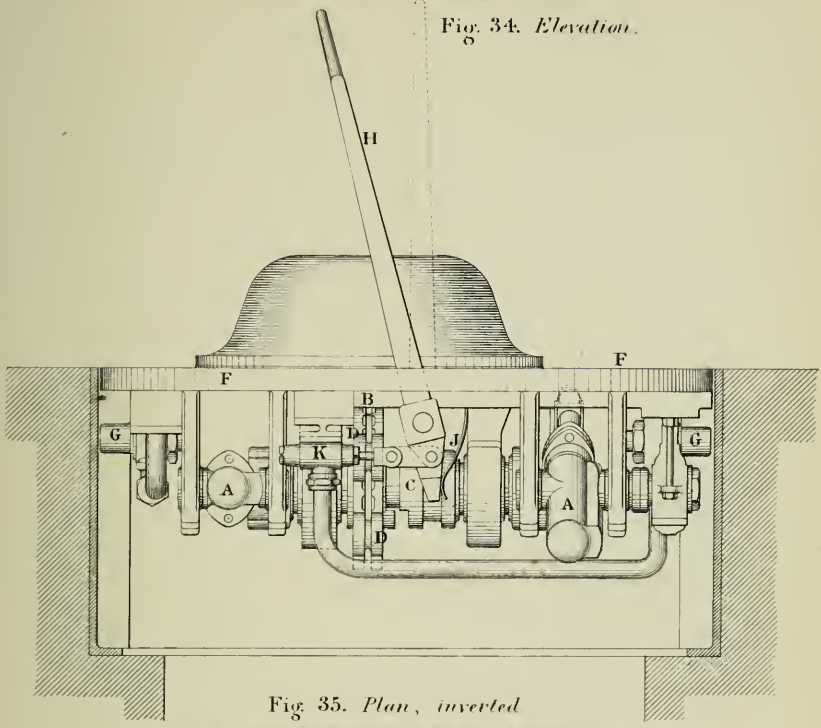
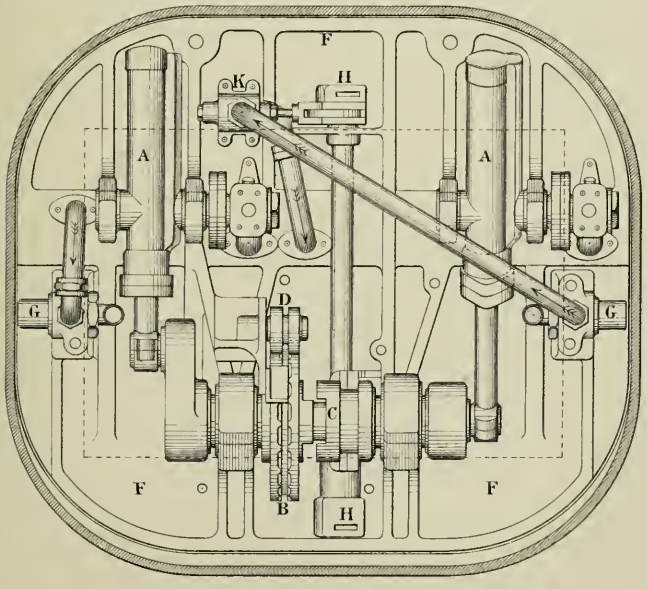


Fig. 35. *Plan, inverted*



(*Proceedings Inst. M. E. 1874.*)

Scale 1/16 *th*

Ins. 12 6 0 1 2 3 4 Feet.

CARDIFF DOCKS.

Portable Hydraulic Crane.

Fig. 36. *Side Elevation.*

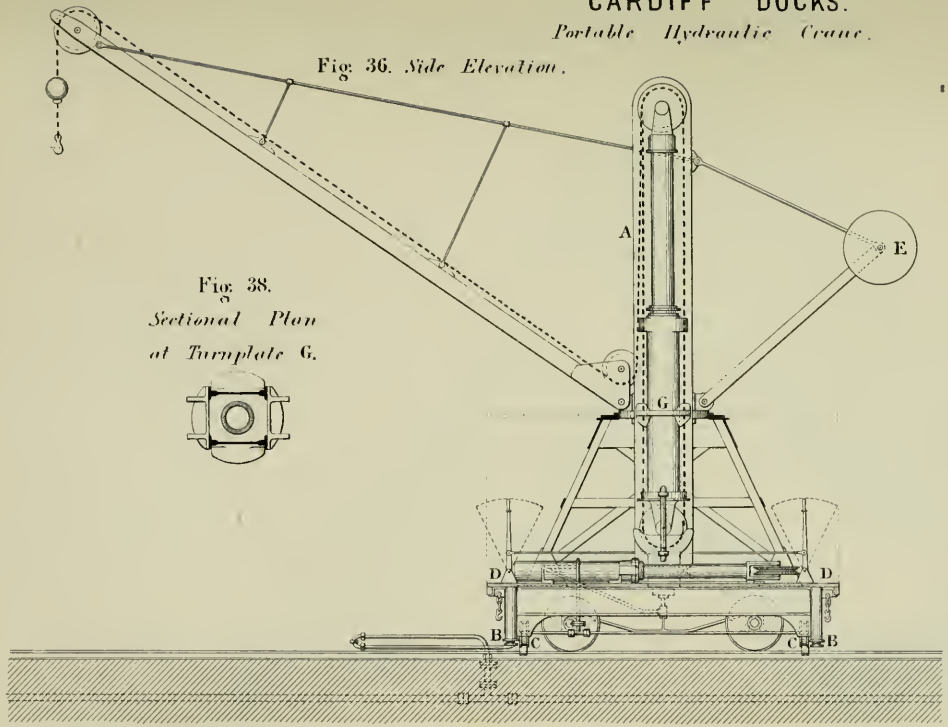
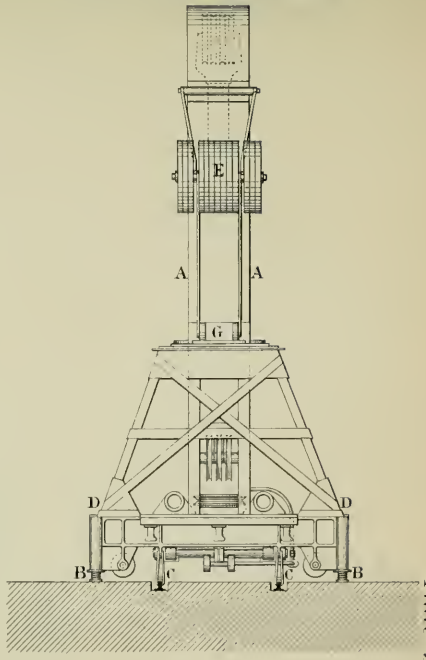


Fig. 38.
Sectional Plan at Turnplate G.

Fig. 37. *End Elevation.*



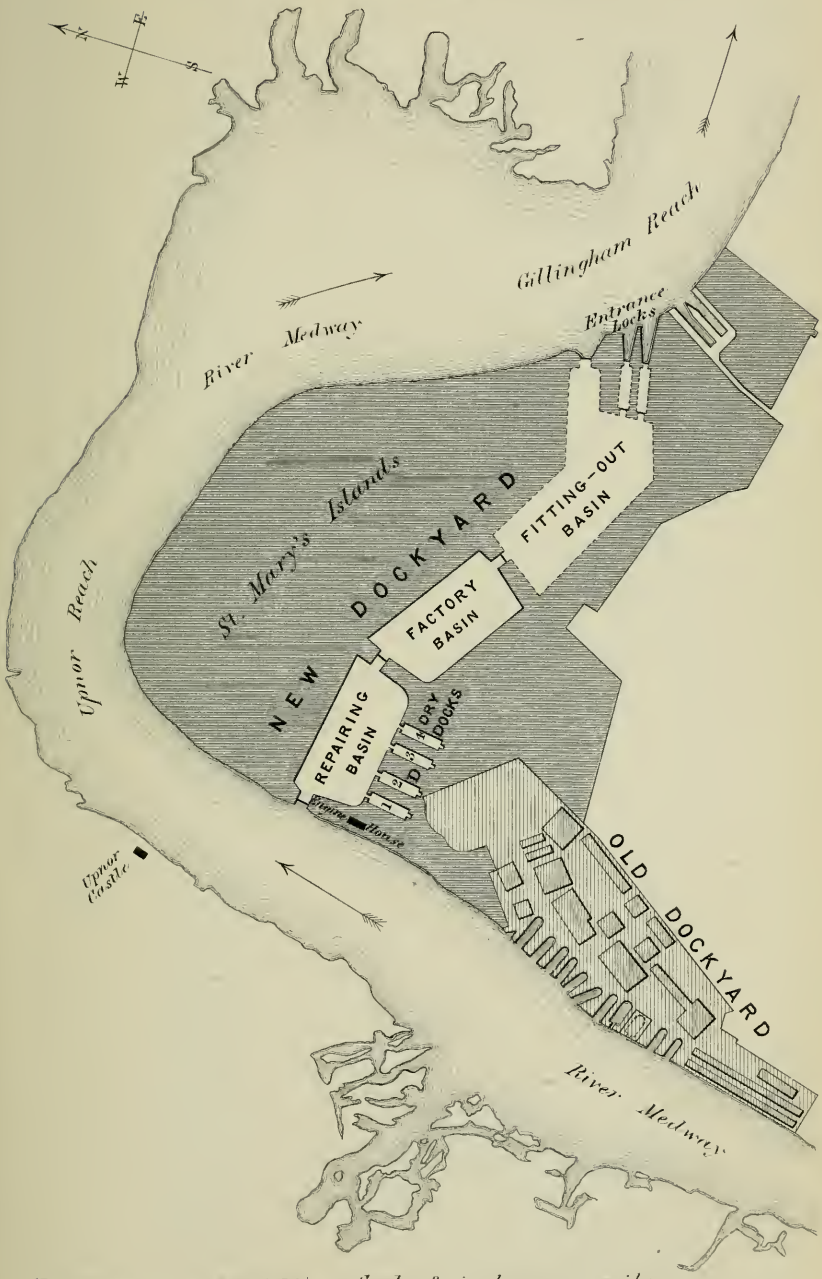
(*Proceedings Inst. M. E. 1874.*)

Scale 1/100 th

10 5 0 10 20 Feet.

Plate 39.

Fig. 1. *Plan of Chatham Dockyard.*



(Proceedings Inst. M.E. 1874) *Scale 3 inches per mile.*

0 1/4 1/2 3/4 1 Mile.

0 1000 2000 3000 4000 5000 Feet.

DOCK PUMPING MACHINERY.

Chatham Dockyard.

Fig. 2. *Transverse Section of Dry Docks, along line of Suction Culvert.*

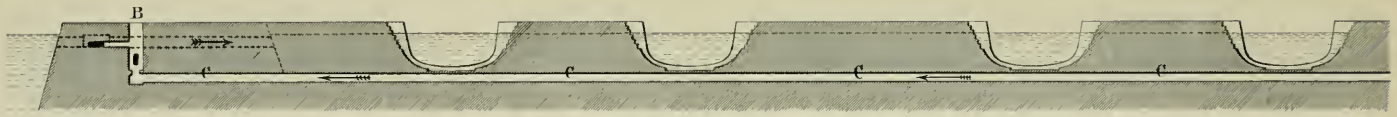
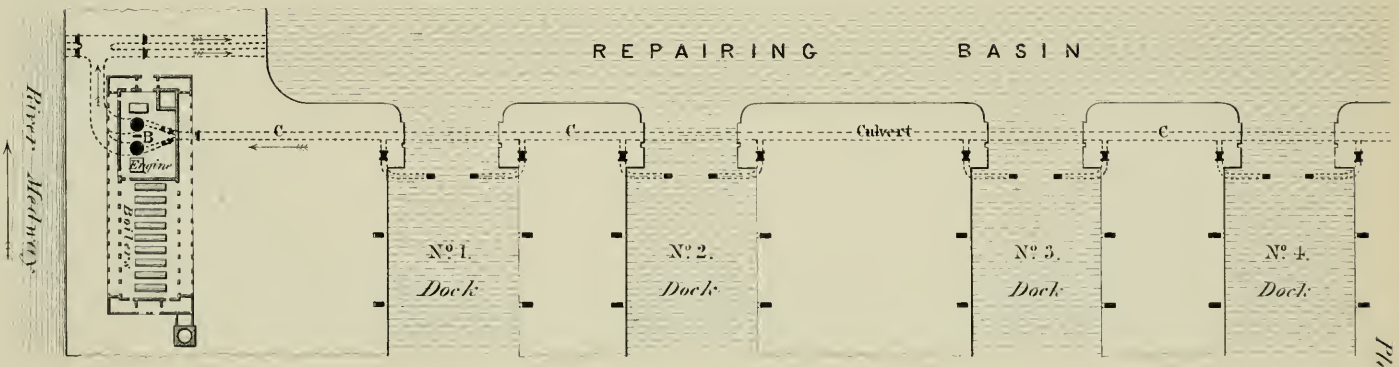


Fig. 3. *Plan, showing Suction and Discharge Culverts and Pump Wells.*



(Proceedings Inst. M.E. 1874.) Scale 1/2000th

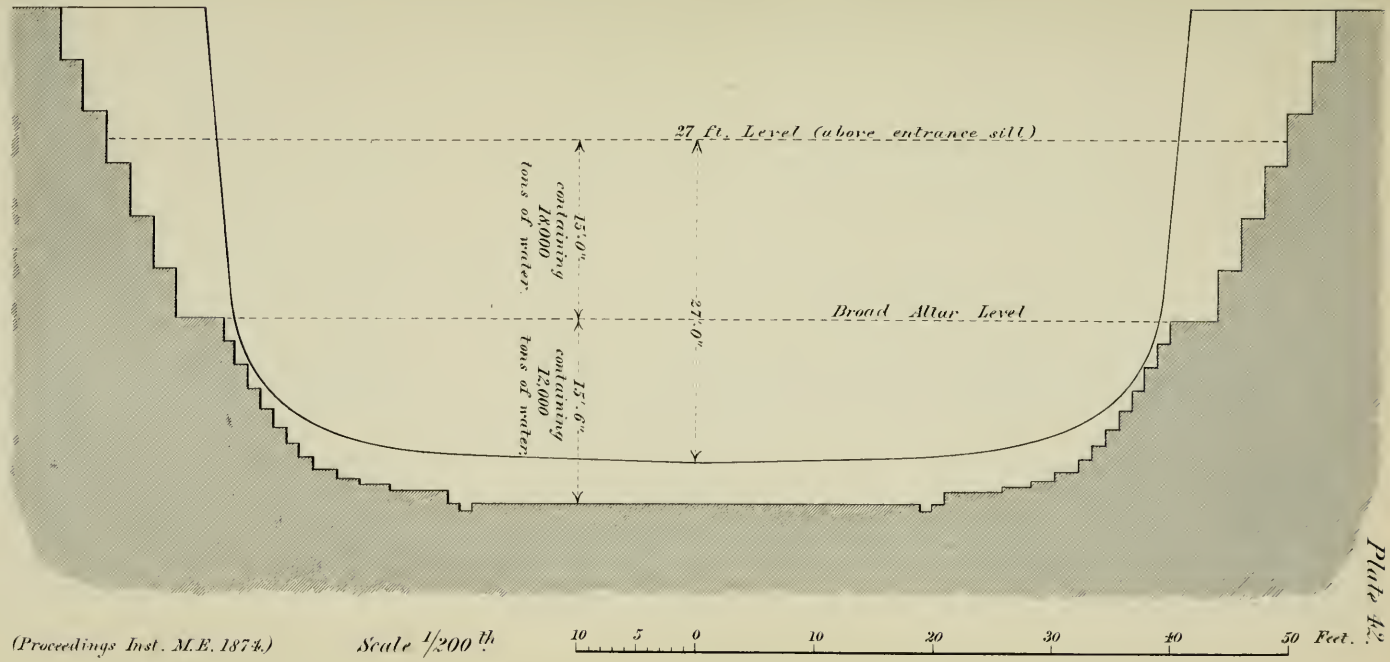
0 100 200 300 400 500 Feet.

Plate 41.

DOCK PUMPING MACHINERY.

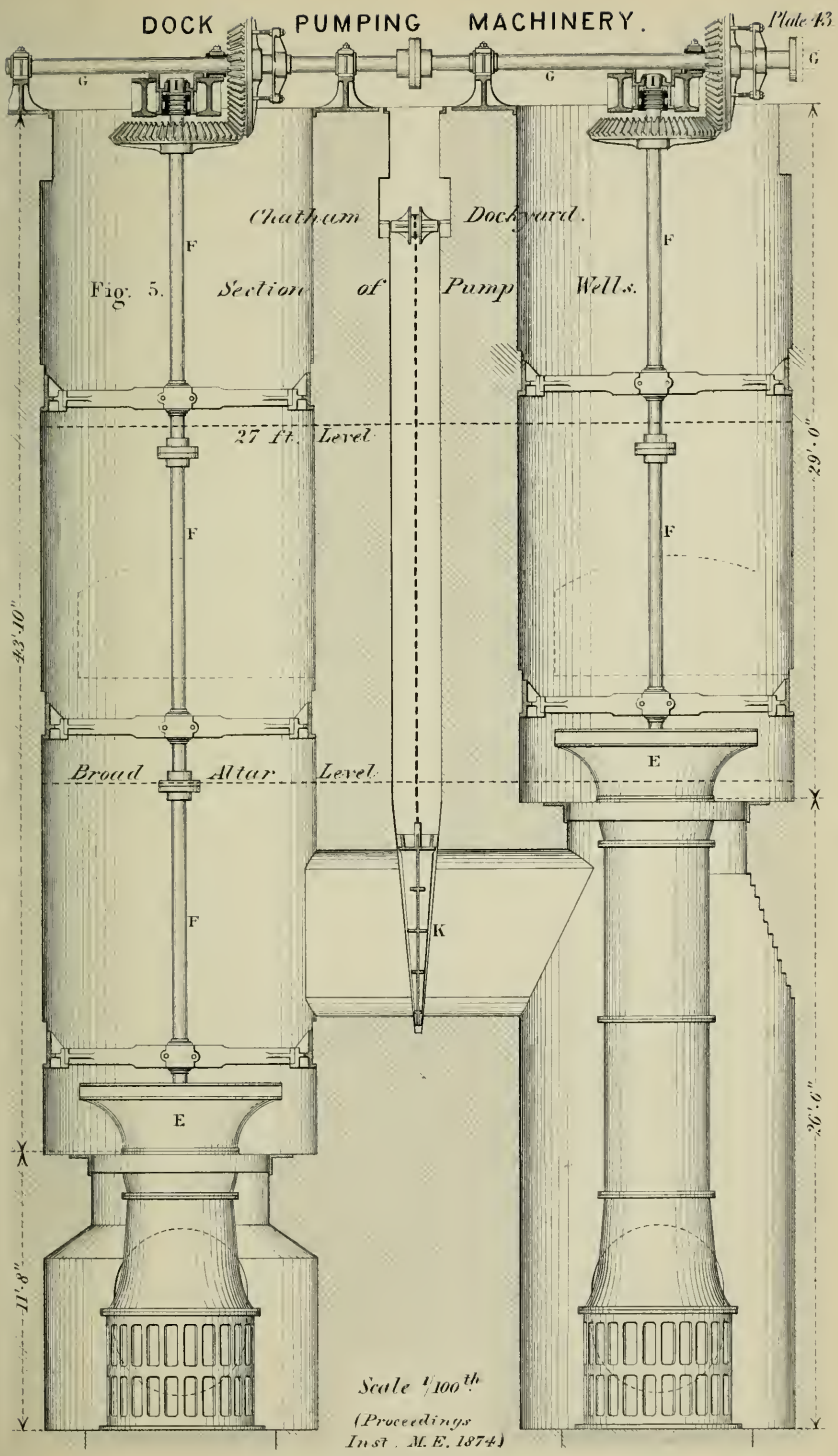
Chatham Dockyard

Fig. 4. *Transverse Section of Dry Dock.*



(Proceedings Inst. M.E. 1874.) Scale 1/200th

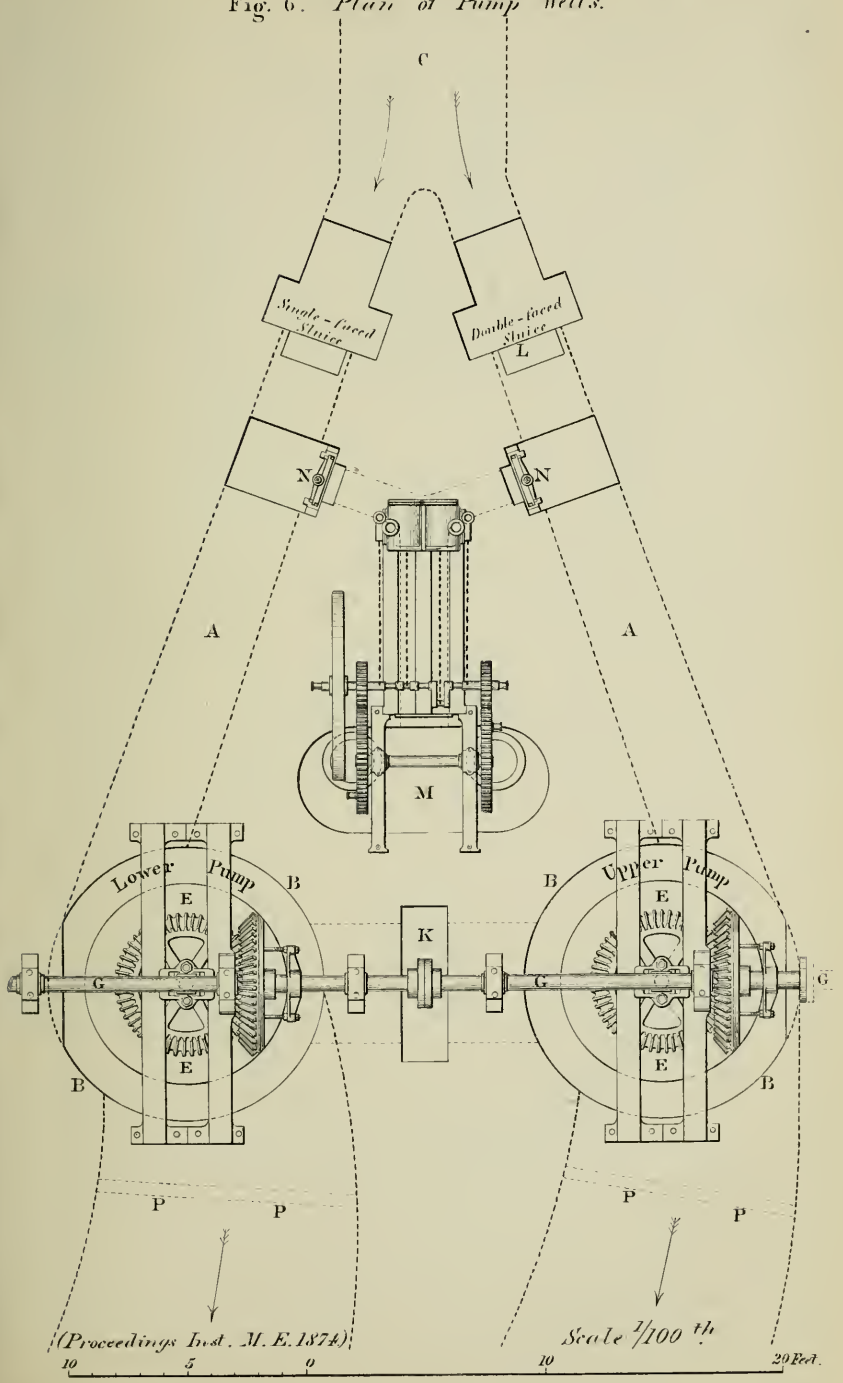
Plate 42.


DOCK PUMPING MACHINERY.
Plate 43
Chatham Dockyard.
Fig. 5. Section of Pump Wells.
27 ft. Level
Broad Altar Level
43'10"
29'0"
36'6"
11'8"
Scale 1/100th
(Proceedings Inst. M.E. 1874)

DOCK PUMPING MACHINERY. *Plate 44.*

Chatham Dockyard.

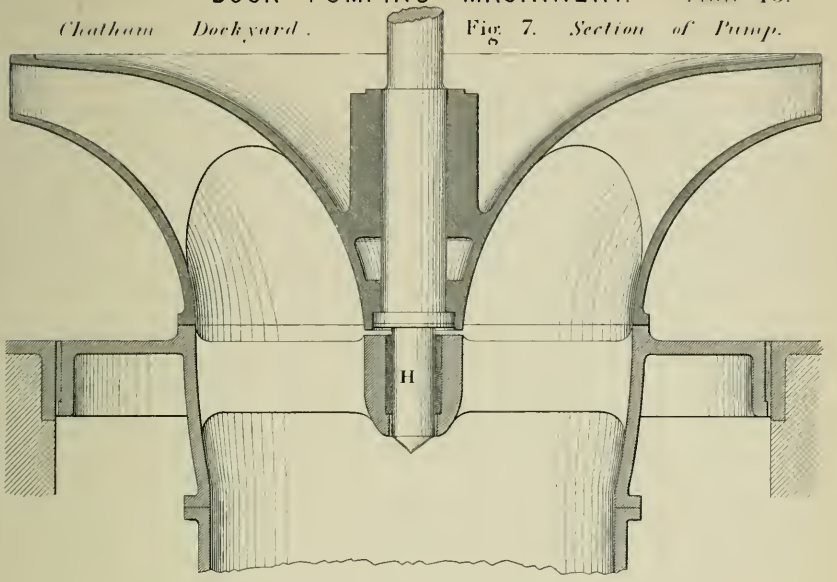
Fig. 6. *Plan of Pump Wells.*



DOCK PUMPING MACHINERY. *Plate 45.*

Chatham Dockyard.

Fig. 7. *Section of Pump.*



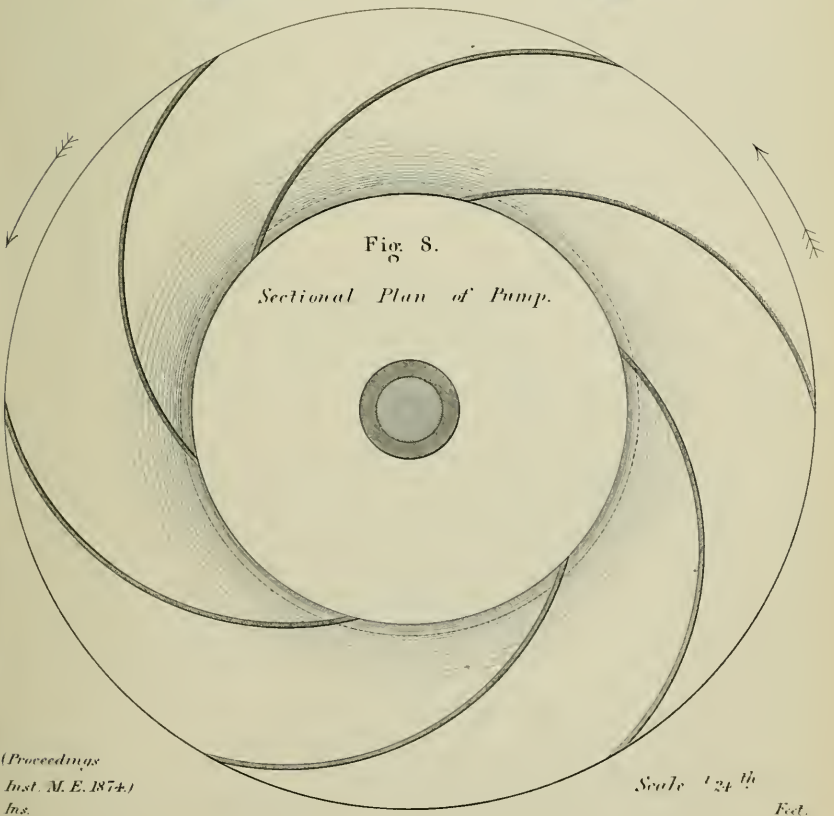


Fig. 8.

Sectional Plan of Pump.

(*Proceedings Inst. M. E. 1874.*)

Scale $^1/_{24}$ *th*

Ins. 12 6 0 1 2 3 4 5 6 7 *Feet.*

DOCK PUMPING MACHINERY.

Chatham Dockyard.

Single-faced Weighted Sluice.

Fig. 10.

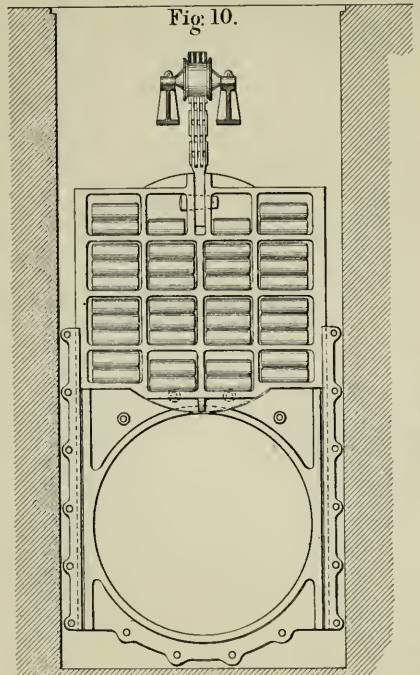
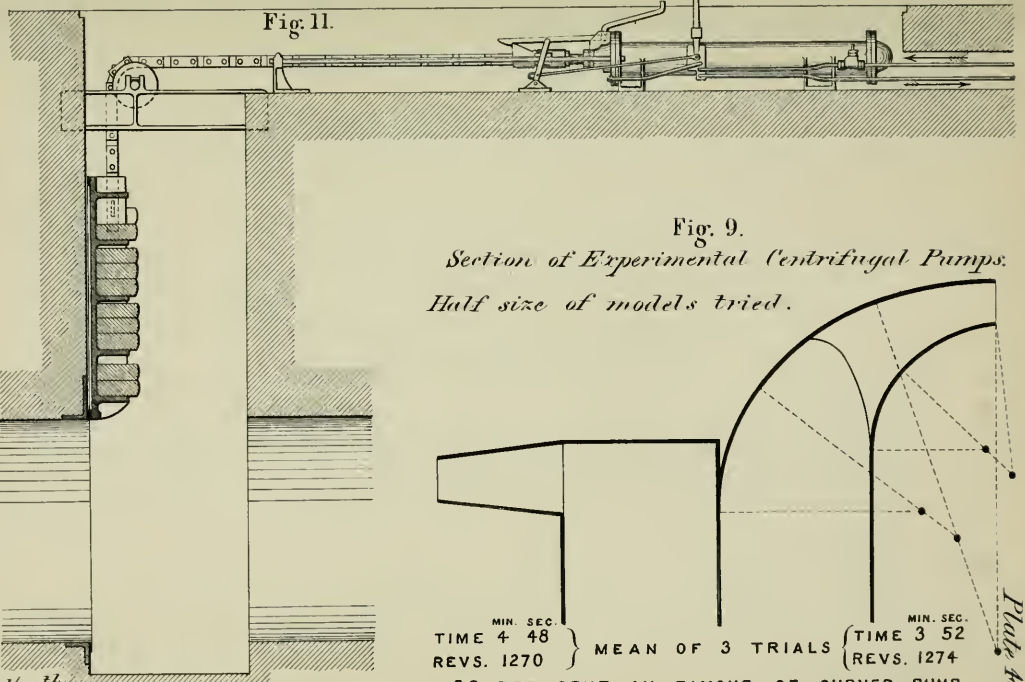


Fig. 11.



Scale 1/70th.

0 5 10 15 20 Feet.

Fig. 9.

Section of Experimental Centrifugal Pumps.

Half size of models tried.

MIN. SEC. TIME 4 48 REVS. 1270 } MEAN OF 3 TRIALS { MIN. SEC. TIME 3 52 REVS. 1274

20 PER CENT. IN FAVOUR OF CURVED PUMP.

(Proceedings Inst. M. E. 1874.)

Plate 46.

Chatham Dockyard.

Fig. 12. *Double-faced Wedge Sluice between Pump Wells.*

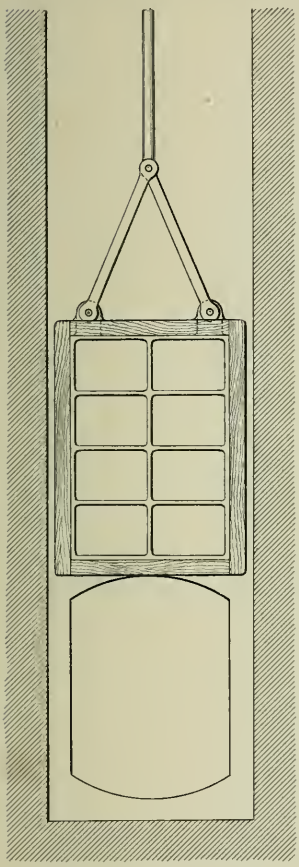


Fig. 13. *Transverse Section.*

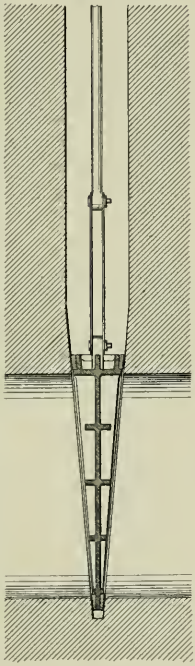


Fig. 14. *Double-faced Sluice in branch suction culvert to Upper Pump.*

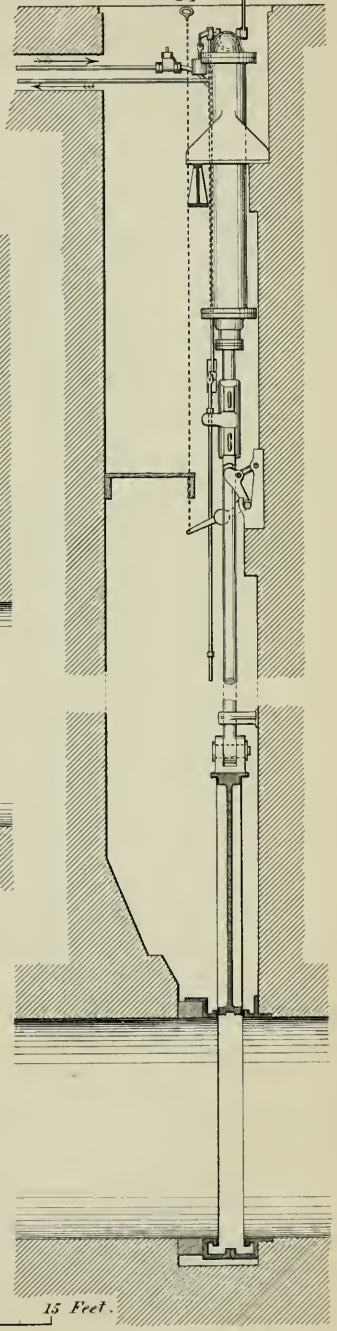
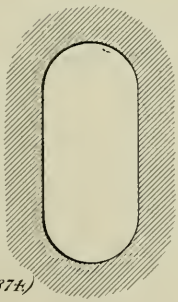


Fig. 15. *Transverse Section of Branch Suction Culverts to Pump Wells.*



(Proceedings Inst. M.E. 1874.)

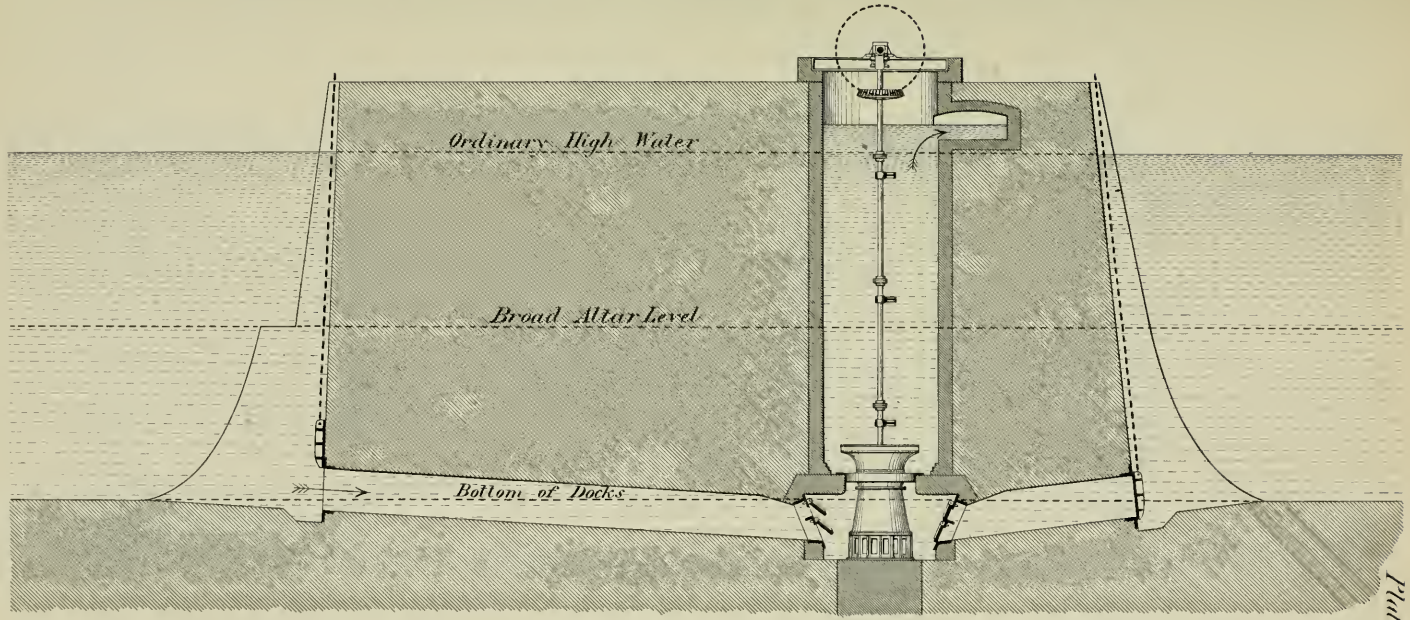
Scale 1/70 th

0 5 10 15 Feet.

DOCK PUMPING MACHINERY.

Rio de Janeiro Docks.

Fig. 16. *Transverse Section through Dry Docks and Pump Well.*

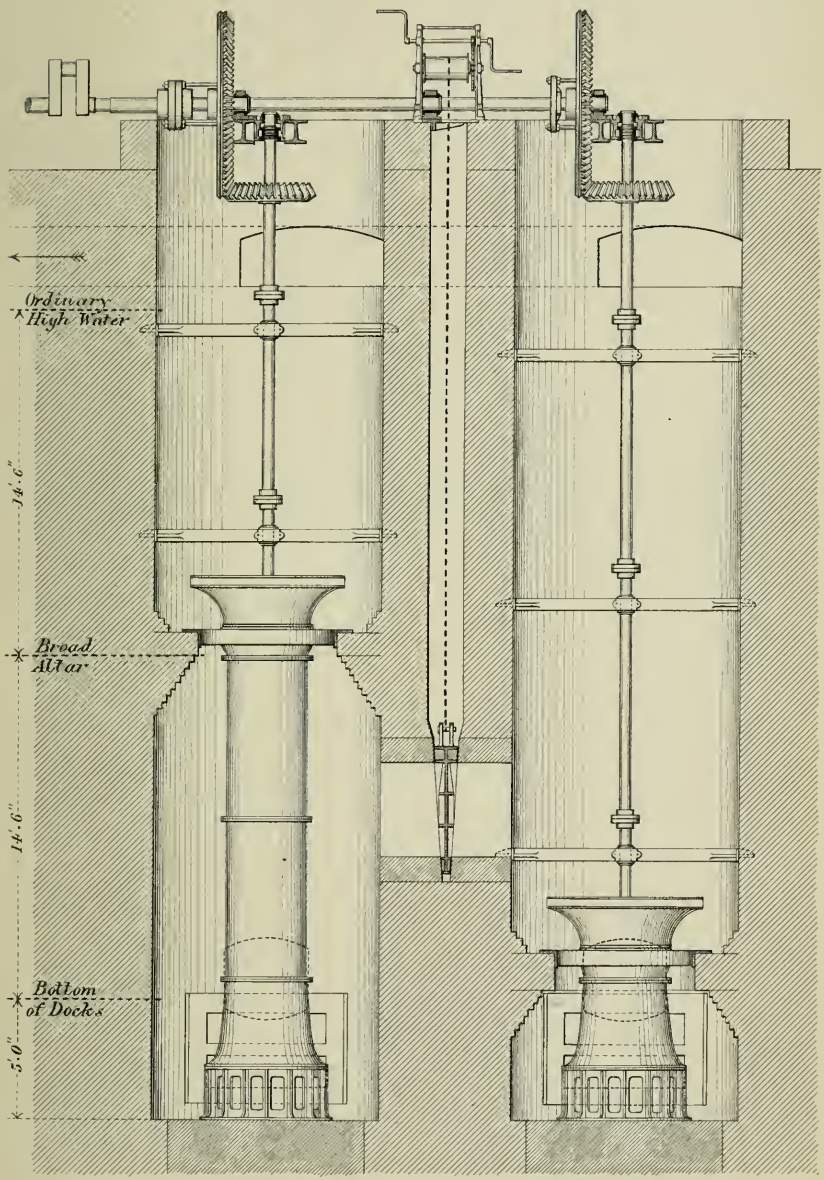


(Proceedings Inst. M.E. 1874.) Scale 1/200th.

Plate 48.

Rio de Janeiro Docks.

Fig. 17. *Section of Pump Wells.*



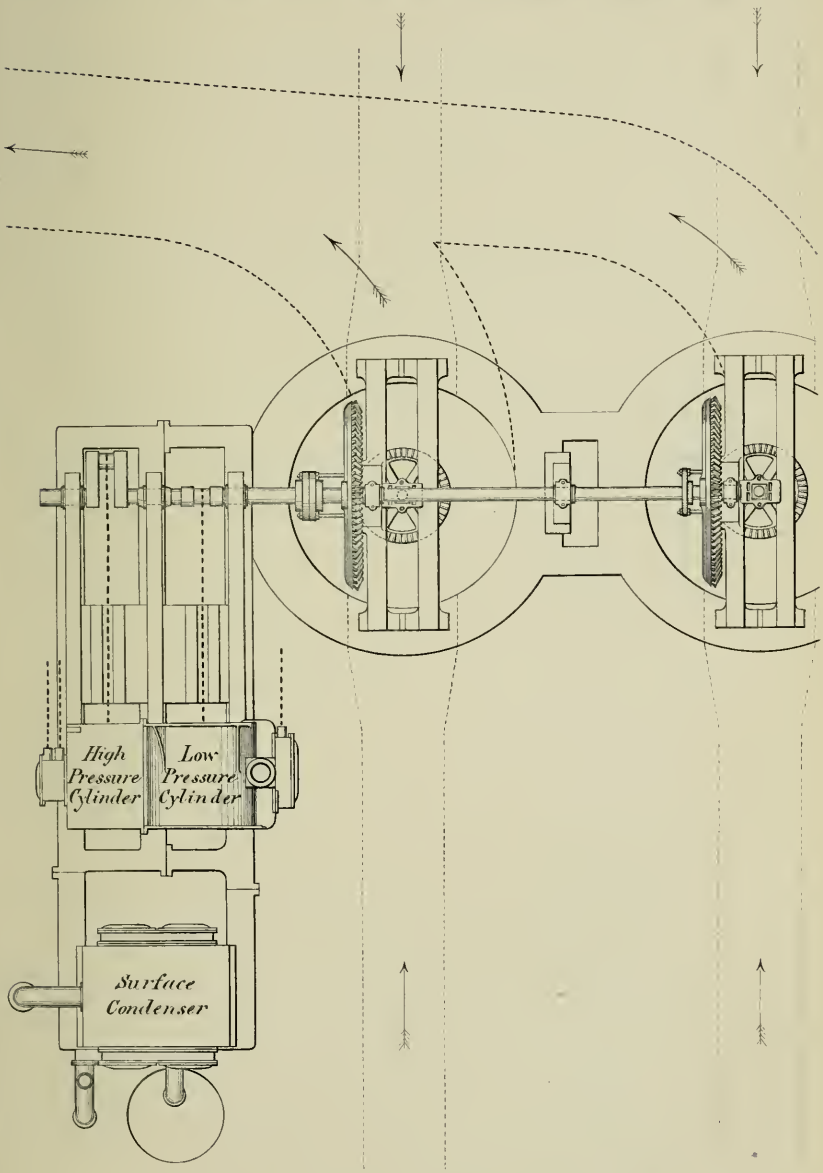
(*Proceedings Inst. M.E. 1874.*) Scale 1/100th

10 5 0 10 20 Feet.

DOCK PUMPING MACHINERY. *Plate 50.*

Rio de Janeiro Docks.

Fig. 18. *Plan of Pumping Engines and Wells.*



(Proceedings Inst. M.E. 1874.)

10 5 0

Scale 1/100th.

10 20 Feet.

PROCEEDINGS.

August 1874.

The Annual Meeting of the Members was held in the Assembly Room, Town Hall, Cardiff, on Tuesday, 4th August, 1874; Frederick J. Bramwell, Esq., F.R.S., President, in the Chair.

The Minutes of the last Meeting were read and confirmed.

The President announced that the Ballot Lists had been opened, and the following New Members were found to be duly elected :—

MEMBERS.

James Abernethy,	London.
Frederick Ayton,	Hexham.
Peter Brotherhood,	London.
William Barber Buddicom,	Mold.
William Edward Burn,	Newcastle-on-Tyne.
Samuel Daw,	Cardiff.
Thomas Deakin,	Manchester.
James Dredge,	London.
John Gjers,	Middlesbrough.
John R. Griffiths,	Pontypool.
William Bishop Harding,	Beverley.
James Hart,	London.
William Hunt, Jun.,	Wednesbury.
James Lees,	Carlisle.
John Milburn,	Workington.
Cornelius McLeod Percy,	Wigan.
Thomas Powell,	Rouen.
Tom Hurry Riches,	Cardiff.

James Lyons Sampson, ... London.
Albert Sauvée, ... London.
Fernando Aramburu y Silva, . . Madrid.
John William Wass, . . . Newcastle-on-Tyne.
Nicholas James West, ... Hayle.
David Williams, ... Pontypool.
Thomas William Worsdell, . . . Crewe.

ASSOCIATE.

Berkeley Paget, ... London.

GRADUATE.

William Collis Rankeilor, . . . Tipton.

The President then delivered the following Address:—

ADDRESS OF THE PRESIDENT.

GENTLEMEN,

You will have seen by the programme of our proceedings that they are to commence by an address from myself, as your President.

In the parent institution of the engineering profession, the Institution of Civil Engineers, it has been the practice for the President on assuming his seat to deliver an address to the members, and many other scientific institutions of more recent date have imitated the civil engineers in that practice; but with us, as you are aware, the delivery of an address is the exception. So far as I remember, during the twenty-seven years we have been an Institution, addresses have been delivered by three only of your Presidents—Sir William Armstrong, Sir Joseph Whitworth, and my immediate predecessor, Dr. Siemens; but as it appears to me that the delivery of an address is a seemly practice, and may be a salutary one, and as for that practice I have the three excellent authorities I have mentioned, I propose to ask your attention for a few minutes while I follow the example they have set me.

The range of subjects that come within the profession of the Mechanical Engineer is so vast, that no President need ever be in any difficulty as to selecting one for an address, should he wish to devote himself to a single topic; but looking at the fact that little has been done in our Institution in the way of addresses, and that thus the ground is comparatively unoccupied, I propose on this occasion not to deal with any particular subject, entering into all its details (useful as such an address might be made), but to consider our profession generally, and our position as individuals in relation to that profession.

Although it is true that by being members of an Institution we acknowledge ourselves to be units in a profession which we thereby recognise as a whole, and although we have in the Institution before us the embodiment in a tangible form, as it were, of the profession, nevertheless I think we are all too apt, in the midst of our own incessant and hard work as individuals, to overlook the fact that we are members of a profession, and to forget its real sterling value; and I think a short time will not be misspent in losing sight of self, and in considering our profession, with the object of setting before our minds its vastness, its usefulness, and its universality, and of arriving at an appreciation of its claims upon us and upon the world at large: in fact, in one expressive word, I wish to occupy a short time in "magnifying" our profession.

What is the profession of the Mechanical Engineer? What is meant by "Engineering?" That question was put, and it was answered, many years ago, by a man whose works on engineering subjects are text books even at the present day—I mean by Tredgold, who for the Institution of Civil Engineers defined "Engineering" to be "the art of directing the great sources of power in nature for the use and convenience of man."

Accepting this definition, let us enquire whether mechanical engineers have to any, and to what extent, carried out and fulfilled the obligations they took upon themselves when they became members of a profession which exercises such an art.

I believe in answering that question we may, without boasting, say, that mechanical engineers, as a body, have to a very large extent fulfilled the obligations imposed on them by their profession.

Let us review as briefly as possible—so briefly indeed as to make the review little more than a list of the names of the subjects we shall notice—what has been done by the mechanical engineer.

Happily for my purposes we may confine our thoughts to a limited range of time; for our profession, unlike those of the sculptor, the painter, or the architect, does not demand of us that we should revert to past ages to find its triumphs: in fact so little is to be gleaned from antiquity that I will not be tempted

even by the name of Archimedes to advert to ancient engineering; but I will at once limit myself to a time so recent that it shall not carry us back to a date anterior to the lives of some of our present members—not anterior indeed to the lives of two of our Past-Presidents, Sir William Fairbairn and Mr. Robert Napier—who both have, happily, contributed their fair share, and more than their fair share, to engineering progress. I will even take a shorter period than that included in the lives of our venerable friends, and will ask you to bear with me no longer than while I mention some few of the leading mechanical features belonging to the 19th century only.

To commence with that which is still the masterpiece of mechanical engineering—the steam engine—I cannot say that it has been invented within this period, because doubtless it existed some little time before, not only for pumping purposes, but also, to a very small extent, for manufacturing purposes; but I may safely say that its practical application to these latter purposes has taken place within this century. Steam navigation is of even more recent origin; while the beginning of railways is, to men of my age, as it were a thing of yesterday; and the establishment of the electric telegraph is within the recollection of all but our youngest members.

The science of sanitary engineering, although claimed, and perhaps properly claimed, by the civil engineer, depends so largely—especially in those parts of it which relate to the distribution of water, and to warming and ventilation—upon the aid of the mechanical engineer for pumping engines and for other purposes, that it demands to be mentioned among the matters connected with our profession: as does also that which is almost a branch of sanitary engineering—the distribution of light by those gas works which from first to last are the product of the mechanical engineer's skill. The supply of water by the aid of the mechanical engineer dates, it is true, from long before the commencement of this century; but the steps that have been made towards the perfecting of such a supply are so great that the

subject may almost be regarded as if it were entirely comprised within the period of which I am speaking: while the practical manufacture and transmission, though not the very first production of gas, are quite within that period; as is also (when considered as a science) the getting rid of our sewage.

But to the mechanical engineer we owe the laying on not only of light, as that word is ordinarily understood, but we owe to him the greatest improvements in laying on light to the mind; for we owe to him the steam printing press, a machine which has been developed from the early invention of the father of one of our oldest and most distinguished members—one of the founders of this Institution, Mr. Cowper—to the admirable machine by which the "Times" newspaper has for some years past been printed; and if the mechanical engineer had done no more than invent the steam printing press, he would be justly entitled to the gratitude of the whole world. But the steam printing press would have been an useless implement if paper had not been forthcoming in proper quantity and in proper form. Hand-made paper might have sufficed, and did suffice for earlier constructions of printing machines; but the machine-made paper, another invention of the period under consideration, is, as you all know, an indispensable adjunct of the "Times" printing machine, as one of the great excellences of that machine is that it dispenses with the intermittent feed of separate sheets, and substitutes for it the ceaseless feed of a continuous sheet of many miles length.

Within this century, in fact within the last few years, we have had the mechanical engineer largely aiding the civil engineer. I have said "aiding;" but in one instance at least, "aiding" is far too weak a term to apply to the position of the mechanical engineer in relation to the civil engineer, for it would not be too much to say that by the production of the locomotive engine the mechanical engineer "created" the civil engineer, so far as that important branch of the civil engineer's business—the making of railways—is concerned. In numerous other matters we have had the mechanical engineer really "aiding" the civil engineer, and especially in those appliances which have rendered practicable the

performance of subaqueous works, such as our forefathers never would have dreamed of as possible. We have had him aiding the miner and the collier, and we have had him by improved machinery aiding the metallurgist; and under this head it will suffice to mention the names of Neilson, Bessemer, Siemens, and Nasmyth, famous for their respective improvements in furnaces, in decarbonising iron, and in treating the produce of the furnace, when that produce is malleable, by the steam hammer. And were it needful to prove to you the vast scope of the mechanical engineer's profession, I might do so by taking, in contrast with such an improvement as that of the huge steam hammer, the delicate mechanical inventions which have been applied to the production of the finest thread, and to the use of that thread in the sewing machine: in fact the talent of the mechanical engineer may be likened to the trunk of the elephant, which, as we all know, has been said to be competent to "root up a tree or to pick up a pin." The matters I have as yet noticed have all been connected with the peaceful arts; but the mechanical engineer has not confined himself to these alone, for we have had men—members of our body, Past-Presidents of this Institution, Armstrong and Whitworth—devote their powerful minds to devising weapons for enabling us to defend ourselves against aggression.

I will not detain you by more instances. I cease from further enumeration, not because the subject is exhausted, for that is well-nigh impossible, but because I am sure I have said enough to show you that within the present century the profession of mechanical engineering has produced inventions of the highest value. But if the list of those inventions is all but inexhaustible, that of the objects to which those inventions are applicable is absolutely so; and thus, as it is impossible to make any summary of them, I will in sheer despair at their multitude content myself with a bare recital of a few only of the benefits that we receive from those applications.

I will begin with mental benefits—benefits in the interchange of thought; and will take only one branch of them, that of the publication and transmission of news. Let us look how this is accomplished. The railway or the steamboat brings detailed

intelligence, the essence of which however has reached us before by the electric telegraph. The news is put into type, but even this is now done by the aid of machinery, which arranges the separate loose types in their proper order. From these is taken a paper mould, in which castings of stereotype metal are obtained in quick succession, and in the course of a few minutes, by the aid of the planing machine and the lathe, these castings are fitted into the steam printing presses I have mentioned; and thus in less than an hour after the completion of the "composition" four or five presses may be at work, printing each their 10,000 copies an hour. No sooner is the printing done than the railway again comes into play to distribute the papers throughout the country; and the telegraph also comes into play to furnish copious extracts of all the principal matter to the newspapers of the provinces.

To the railway, to steam navigation, and to the telegraph, we owe the breaking down of the barriers called space and time, which separated nations and individuals; and to these inventions therefore we owe the enormous extension of commerce and of personal communication.

By the aid of the mechanical engineer we obtain our fuel; for not only is he required in keeping our mines free from water, in raising the fuel to the surface, and in maintaining efficient ventilation, but to him we owe such machines as those of Mr. Firth and others, by which the most trying part of the labour of getting coal is transferred from sensitive humanity to inert iron and steel. To the mechanical engineer we owe, by the aid of the fuel so obtained, the mastery over all the intractable metals: whether, as in the case of cast iron, extracted from the ore in the furnace with its heated blast, and delivered in the form of "pigs;" whether converted from that form by streams of air at high pressure, as by Bessemer; or whether obtained from the ore at once, in the form of steel or iron, as by Siemens. And having got the metal separated from the ore, to the mechanical engineer we owe the shaping of it into all the desired forms, whether for rails, ships, guns, or engines, or for use in our dwellings; and as regards the other materials we employ in those dwellings, the inventions of the mechanical engineer dress

the stone, make the bricks, saw and plane the timber, and mould it into gracious forms. As for our clothing, from the very coarsest fabric to the most delicate lace, the hand of the mechanical engineer has been engaged on every stage of the manufacture, and the materials thus made are united to form garments by the now all but universal sewing machine—a machine which in itself is a study, and has varieties so great as to enable it to cope with the finest fabric, or even with the thick and obdurate leather forming the sole of the stoutest boot. And further, not only do we owe to the mechanical engineer the preparation of our dwellings and of our clothing, but we owe to him the very greatest aid in the production of our food, for it is with his assistance that we till the ground, that we sow it, that we cut the crop, thresh out the grain, and convert the product into bread: in short it is no exaggeration to say that there is no one want, no one comfort, nor even one luxury, that is not either directly or indirectly dependent on the mechanical engineer for its production, or for the bringing of it within our reach.

I have thus in as condensed a form as possible noticed some few things that mechanical engineers have invented, and some of the results which flow from the use of their inventions; and I think that a consideration of these inventions and of their uses must make us all proud of our profession. I know that pride is commonly held to be bad, or, if not absolutely bad, to be dangerous; but there is to my mind the greatest possible difference between individual pride and pride in one's profession. In the case of individuals we must all appreciate the value of modesty; and it seems to me that modesty may—in fact must—be a result of the very pride we take in our profession. For when we reflect upon it, it becomes impossible for any one of us to refrain from asking himself, "What have I done to advance our profession?" and it becomes equally impossible to refrain from being humiliated by the reply, for the very best of us must answer, "I have done but little," and most of us must answer, "I have done nothing." And thus it is that, as I have said, a consideration of the dignity and importance of our profession is the means of all others to make us as individuals modest, dissatisfied with ourselves, desirous of doing better.

With respect to the desire of doing better, I am aware one is apt to say, "What chance have I? What is there great that is left to be done? Those men who have gone before have anticipated me; the grand substantive inventions and improvements have been made by them; they have reaped the harvest, and there is nothing left but the corners of the field for me to glean." But this feeling, although natural, is one that should not be yielded to. Depend upon it, such a feeling is the suggestion of our evil genius; for although I cannot indicate to you what will be the grand inventions that will be made in the course of the next fifty years (for if I could I should go a long way towards being a great inventor myself), nevertheless we know that within that period great inventions will be made; and we are sure that any one who fifty years hence looks back on the condition of engineering science at the present time, and compares it with that which he will then know, will wonder how it was that the men of this day failed to make many a grand discovery, which at that time, to him, will be as familiar as the steamboat or the locomotive is to us. But although I am necessarily unable to predict to you what will be the great substantive inventions of the future, it is within my power to remind you of many useful directions of improvement.

First of all comes the great question of the preservation of our coal, which, at the risk of impropriety in repeating myself, I must call the very "breath of the nostrils" of our principal machine, the steam engine. About 120 millions of tons of this most valuable substance are raised to the surface in our small island every year. Such a quantity as this fairly staggers the imagination, it seems incredible that the deposits below this minute portion of Europe can long hold out against so great an annual attack; and we cannot help asking ourselves, "Is this quantity honestly used? Is it honestly got?" By that primary question, "Is it honestly got?" I do not mean honestly in the dry legal sense; that is to say, I do not mean that any law is infringed, or that any person is doing wrongfully so as to be amenable to our courts of justice; but I mean, is it got honestly as between man and man—as between ourselves and those who are to come after us? Do we not work

coal pits with no other object than that of obtaining the utmost present profit out of them? Do we not thereby leave behind the less immediately valuable coal, and leaving it unassociated with that which is more profitable, render it all but impossible for those who come after us to get, except at too great a cost? Whereas we might, by a small present sacrifice, extract a great deal of that which now we think not worth obtaining; and cannot the skill of the mechanical engineer come in here to work seams which manual labour is not able to touch without the reduction of the present gain? I will say no more on the subject of "getting" coal, as I do not wish to trench upon the special province of our brethren, the North of England Mining Engineers, who we are happy to know are holding their meeting in this town contemporaneously with ourselves.

Coal is one of "the sources of power in nature." It may be considered (as our first President, George Stephenson, suggested nearly thirty years ago, and as our last President, Dr. Siemens, referring to this suggestion of Stephenson's, fully explained in his lecture at Bradford) the representative of the stored up heat of the sun; and it is part of our art to direct that source of power for the use and convenience of man, and we have so directed it by employing it in the steam engine. But have we not, in consequence of the facility of its application, been tempted to neglect other sources of power in nature? Do we sufficiently utilise the waterfall, the tidal wave, and the force of the wind? And, with respect to the employment of these forces, we should remember that we are enabled to utilise water power in a way which to the engineers of the last century was unknown. They availed themselves of the waterfall—indeed it was their chief source of motive power—but they were compelled to place their manufactories close to the falls; we however know that it is perfectly possible to transmit (at some cost by loss of power, it is true, but not at a prohibitory cost) power to very long distances. The transmission, so far as invention has at present gone, may be made by exhaustion of air, as practised by Hague forty years ago, by the compression of air, by rocking rods, by swift-running wire

ropes, and by the employment of water under pressure, as practised by Sir William Armstrong. But do we resort to all these facilities for transmitting power from a distance? Do we resort to any large extent to sources of power in nature, other than coal? Is it not the fact that mechanical invention has gone back in these matters rather than forward? And do we utilise that primary source of power, the heat of the sun—the current heat from year to year,—making the most of barren hill sides, as it seems to me we might do, by planting quick-growing trees, which, fostered and matured by the sun, would yield large quantities of wood to be used as fuel for domestic purposes? Are we estimating at their full value the deposits of peat, and are we not tempted to pass by this large store of fuel because its use is attended with difficulties? In those cases where coal must be used for power, has it not to be admitted that in far too many instances it is recklessly, wickedly employed; that the engines are in their design and construction disgraceful, and that a consumption obtains equal to four, five, or even ten times that which would suffice with proper engineering care? In the same way, when we employ coal for heating purposes only—such purposes as metallurgical operations demand,—is it not in too many instances used in the most grossly wasteful manner? How much of the fuel goes up the chimneys of our furnaces unconsumed, in the form of visible carbon, or in the worse because less readily detected form of invisible carbonic oxide? How much of the heat of the coal which is consumed escapes uselessly into the air in jets of flame, which in the night time throw their light around for miles? It cannot be doubted that we have been and still are (although I believe and trust we are improving) most cruelly wasteful, and, as I have said, wickedly wasteful. It pains me when I hear a man talk of "only a bit of coal." He cannot think of what he is saying. "Only a bit of coal!" Only a bit of that which might have helped to gladden some man's fireside. "Only a bit of coal!" Only a bit of that, which, if not wasted but properly used, might have helped and might have succeeded in saving some noble vessel with all its brave crew from perishing on a lee shore. "Only a bit of coal!" Only that which might have assisted in wringing the

bright metal from the sullen dross with which it had been associated for countless ages. "Only a bit of coal!" Only that which has been got at the peril of men's lives, and not at the mere peril but at the actual cost of men's lives, for ten men die violent deaths for every million of tons raised. "Only a bit of coal!" Only part of the store which the Almighty had buried in the recesses of the earth to be treasured up there for the honest and reasonable use of generation after generation. It really is grievous to hear men talk slightingly of "only a bit of coal;" and I think it becomes us mechanical engineers, by precept, practice, and example, to do all that lies in our power to cause all to respect and to understand the value of that which they have but too long lightly treated and grossly abused.

I feel I owe you apology, or at least explanation, for the remarks that I have made upon the saving of coal, because remarks of this character have of late years been made by others than myself, and I personally have made them before another scientific meeting; but the truth is that my mind is so forcibly impressed with the importance of the question that I hardly know how to refrain from alluding to it, especially when I have the opportunity, as I have now, of addressing a body who of all others are those who can do most towards curing the evils of which I have complained. And further, in excuse of my having to some extent repeated myself on this subject, I will ask you to remember that, however important a reform may be, it is not brought about by a single statement, although the facts contained in that statement may be absolutely incontrovertible; but that improvement and reform need, for their carrying out, repetition and reiteration of the circumstances which render such reforms necessary.

I have occupied so much time in this question of the savings which might be effected in the getting and in the use of coal, that I must restrict myself to but a few words in alluding to some other directions of improvement within the scope of our profession. One of these is the substitution of mechanical force for manual labour in all cases where the labour is that which,

though rendered by man, does not demand the exercise of human intelligence—mere brute labour,—as when men are employed to raise weights. We are however so used to this that we are not shocked at the sight of a man turning an ordinary crane; but when, as in years gone by might have been seen in the London Docks, and when, as I have recently seen on the Continent, men are performing the same task by working inside a tread-wheel and causing it to turn, we involuntarily think of the turnspit, and are compelled to admit that this is mere brute labour—labour indeed to which we put our convicts as a punishment; and we feel that a man like Sir William Armstrong, who by his invention transmits the force of a central engine in some large dock, or on a quay side, to all the cranes and hoists within its area, is a benefactor to the human race, because, hard though it may be at the time of the change, he has by his invention rendered it impossible for a man to earn his bread by the exertion of muscular strength without the exercise of intelligence, and thereby Sir William Armstrong is doing a real service to the progress of humanity. There is another class of labour, which, although it demands high skill, and therefore does not come within the category of brute labour, but is far from it, yet on account of its fatiguing and exhausting nature we should wish to see superseded: I allude to such labour as that of the hewer of coal, and to such labour as that of the puddler. In these two instances however we are happy to know that we are far on the track of substituting mechanical appliances for the arm of the workman.

Then there are open to our members improvements in the comfort and in the safety of our travelling by land or by sea. I trust I am not too sanguine when I say that I hope for greater speed in both those modes of journeying; for greater comfort, even in the mastery of sea sickness; and for greater safety, by better signals, by improved modes of communication between those on the train and those in the station or signal houses, and by better means for rapidly and safely arresting the speed of trains. Again, I think we may look for more satisfactory

modes of uniting materials. In the constructive arts there is no doubt that the uniting of the materials is as supremely important a part as in the construction of a sentence is the verb; in fact it is a mere truism to say that without the means of uniting, construction is impossible, unless construction were confined to that of those former ages into which I have said I would not travel, where it meant little more than placing one stone upon another. It is, I must say, a disgrace to mechanical engineering that we cannot unite such materials as iron or steel without the barbarous expedient of cutting away a large percentage of their strength by making holes to admit of the insertion of bolts and rivets; and we ought to be able to devise means of union by welding, which should almost entirely supersede our present very primitive mode of procedure.

The foregoing are all matters for ourselves alone, but there are others where, either alone or in conjunction with the chemist, there is obvious room for improvement: such are the making use of the so-called, and in most cases most improperly so-called, "waste products" of our various manufactures; such are the getting rid of gases and fumes deleterious to health; such are the obtaining of purer water in our dwellings; and such are the saving of metal in metallurgical operations, for too surely do we now needlessly waste in many of those operations the very metal which should be their product. I will not continue further these suggestions, but will only repeat that in the absence even of great substantive discoveries, such improvement affords wide scope for the mechanical engineer, and therefore the prospect of those who are to follow us is by no means a gloomy one. And it must be remembered that those men will come to the exercise of their profession with advantages which very few of their predecessors possessed. Most of us have had to rely on our innate love of the profession and on our mother wit for all that we have done. Technical education in our youth was a thing unknown, and scientific education fell to the lot of but few; but those who succeed us have—or if they have not, it is their own fault—the advantages, which were denied to us, of scientific training;

and therefore, as I have said, they not only have a wide field before them, but there is good reason to believe that by their training they have every facility for cultivating it.

While on this subject I cannot refrain from saying that the success of the men of the past generation, in the absence of special training, was I believe in a large measure due to this, that they became engineers literally because they could not help it, that the taste for engineering was born with them, and that their very natures compelled them to follow that taste. And when men enter the profession from such causes as these, it is not surprising that they succeed, even in the absence of extraneous aid. But nowadays it is too commonly the fact, I am afraid, that a man becomes a mechanical engineer as he might become a wine merchant or a stockbroker, because his father wants him to earn his livelihood in some way, or because he has got capital at command, and not because he has the real love of the profession in him. Such a man may succeed, but if he do, he will do it as a mere manufacturer: about whom, and about the subdivision of our profession, I now wish in conclusion to say a few words, as they are both subjects which may prove sources of danger to the advancement of that profession.

Forty years ago the business of a mechanical engineer was general: the man who made a marine engine made a locomotive, made mill work, and made land engines. But within the last few years the business of the mechanical engineer has divided itself into distinct branches, so that the locomotive builder is little more than a locomotive builder, or the marine engineer than a marine engineer. I presume such division is the almost inevitable result of the growth of any industry, and so long as the productions of that industry are not intimately connected with science, separation is probably a thing to be desired, as cheapening the article produced; but in the business of the mechanical engineer, closely allied as that is to science, the separation of his industry into branches appears to me to be dangerous. It narrows his opportunities of gaining knowledge in his profession, and he is in danger of becoming the mere manufacturer. But the division into branches to which

I have alluded must, I am afraid, continue. It is most desirable however that those, who by their commercial practice are devoting themselves to one section alone of the mechanical engineer's business, should as a matter of duty keep themselves thoroughly acquainted with the state of knowledge in all the other sections of our profession, and with the improvements that are being made in those sections; and I know no better means of so doing than by their giving their heartiest co-operation to the advancement of our Institution, by communicating to it all that is useful that comes within their knowledge, and by assiduous attendance at the meetings for the purpose of testing by discussion the value of that which is brought before the Institution, and of adding by their remarks to the information imparted in the papers. But to those of our brethren who are so much absorbed in their business as manufacturers that they care not to devote time to advancing the general scientific position of the profession, I will say that they may still uphold its usefulness, and even its dignity, by the excellence of the products of their manufacture. And let us trust that competition, however keen it may be, and whether between the natives of these islands, or whether between them and the foreign manufacturer, may never drive our members to seek commercial success at the cost of the excellence of their work; but that competition may have the opposite effect, and may make them feel that in a high reputation lies the best hope of excelling and of gain; and thus that competition itself may be the means of causing them to discharge their duty to the profession of which they are members.

I fear that in this address there are to be found occasionally the tones of caution or even of censure mingled with those of exhortation; but if this be so, it has arisen from my desire to bring before you that which I believe to be the truth. It is well that some one should bring the truth before us from time to time; and that in this instance it has been done by me is the result of your own act, because it is you who have selected me as President of the Institution. I find that I have spoken to you at greater length than I had intended—at such length indeed as to make me feel

I have incurred the risk of wearying you, and of taxing your patience by keeping you from the regular business of the meeting; but I shall not have incurred that risk in vain, if I have succeeded in that which I set myself to do at the outset, namely to divert your minds for a short time from individual interests and pursuits to the consideration of the broad features and aims of our noble profession, and if in any way I have stirred you up to resolve to do all in your power to advance that profession to which we are all I trust proud to belong—the profession of the Mechanical Engineer.

The following paper, by Mr. John McConnochie, Engineer to the Bute Harbour Trust, was then read:—

ON THE BUTE DOCKS AT CARDIFF AND THE MECHANICAL APPLIANCES FOR SHIPPING COAL.

By Mr. JOHN McCONNOCHIE, of Cardiff.

Description of the Docks.—The construction of the Bute Docks at Cardiff and the consequent rapid growth of the town are due to the remarkable foresight and public spirit of the late Marquis of Bute, who in the year 1830, finding the great mineral wealth of the adjoining district of South Wales locked up by the want of railway conveyance to the sea coast and proper means of shipment, resolved upon the construction of a dock on the foreshore at Cardiff, the only accommodation then existing for vessels being the Glamorganshire Canal, with a limited capacity available only for vessels up to 200 tons.

The original design of the Engineer, Mr. Green of Exeter, was to place the entrance gates on the foreshore at a point near the end of the present low-water pier, shown on the general plan, Fig. 2, Plate 24; and to construct a ship canal across the foreshore to the intended dock on the mainland. The expense and difficulty of constructing such a work at that time led to a modification of the design; and it was ultimately decided, under the advice of the late Sir William Cubitt, to cut an open tidal channel across the foreshore to the main land, and there construct an entrance basin communicating with the dock by means of a lock.

This Dock, now called the "Bute West Dock," Figs. 2 and 3, Plates 24 and 25, was with its sea approach completed in 1839 at a cost of about £400,000, an expenditure which even then displayed the public spirit of the late Marquis of Bute, when the total import and export trade amounted to less than 7000 tons per annum, as compared with $3\frac{1}{2}$ million tons per annum at the present time, showing an increase of 500 times.

The tidal water of the Bristol Channel contains a very large quantity of mud in suspension, which would have involved a heavy expenditure for dredging the deposit, if the tidal water had been impounded in the dock. This consideration led the engineer to fix the level of the dock water at several feet above the high water level of the channel, and to supply the dock with fresh water from the river Taff. The water is drawn from the river for this purpose about two miles inland, and the feeder F, Fig. 2, passes through the town and delivers the fresh water at the north end of the dock, Fig. 3. The entrance channel E across the foreshore is three-quarters of a mile long and about 200 ft. wide. The basin D is 300 ft. long and 200 ft. wide, with an entrance 47 ft. wide from the sea; the lock between the basin and the dock is 152 ft. long and 36 ft. wide. The dock is 4000 ft. long and 200 ft. wide, with 19 ft. depth of water for a length of about 1500 ft., and 13 ft. depth for the remaining length of about 2500 ft. The depth of water on the sill of the entrance gates is 28 ft. 9 in. at high water of ordinary spring tides, and the gates are opened only for one hour before, and about two hours after high water: the gates are constructed of timber. The water area of the dock and basin amounts to 20 acres.

So great and rapid was the increase of traffic after the opening of the Bute West Dock that in 1851 it was decided by the Trustees of the Marquis of Bute to construct a new dock of larger capacity, now called the "Bute East Dock," Fig. 3, Plate 25. This dock has a sea basin 380 ft. long by 250 ft. wide, approached from the entrance channel on the foreshore by a lock 220 ft. long by 55 ft. wide, having a depth of 31 ft. 9 in. on the sill, or 3 ft. more than in the West Dock. The inner lock from the sea basin to the dock is 200 ft. long by 50 ft. wide. The dock is 4300 ft. long, 300 ft. wide for the first 1000 ft., and 500 ft. wide for the remaining 3300 ft. The uniform depth of water is 25 ft., the water level in this dock being maintained at the same level as in the West Dock, by fresh water drawn from the river Taff. The water area of the East Dock and basin amounts to 45 acres. The lock gates were originally constructed of German and English oak; but having

ultimately proved too weak to resist the great pressure of water to which they were subjected, the gates of the outer lock were replaced in 1863 by new gates constructed of wrought-iron ribs, English oak heel and meeting posts, and Dantzic fir planking. This construction, rendered necessary by the limited space provided in the masonry for wooden gates, has proved perfectly satisfactory. A junction canal connects the East and West Docks with the Glamorganshire Canal. The basin and first portion of the East Dock were opened for traffic in 1855, and the remaining length of the dock was completed and opened in 1859. The East Dock was commenced from the designs of Sir John Rennie and Mr. John Plews, and completed from the designs of Messrs. Walker Burges and Cooper.

New Basin.—Notwithstanding this large accession to the dock area of the port, the continued increase of traffic called for further accommodation, and in 1864 application was made to parliament by the Bute Trustees for powers to construct additional dock accommodation; but it was not until 1866 that an act was obtained for the construction of an additional basin, which has been completed from the author's designs, and has just been opened for traffic. This basin is intended as preliminary to an additional dock of 54 acres area, for which parliamentary powers have this year been obtained; and while serving the new dock, it will also relieve and facilitate the working of the traffic of the Bute East Dock.

The New Basin, Figs. 2 and 3, Plates 24 and 25, is 1000 ft. long and 525 ft. wide, having a water area of 12 acres. It is entered from the channel on the foreshore, which has been widened for this purpose, by a sea lock 350 ft. long and 80 ft. wide, shown in section and plan in Figs. 4 and 5, Plate 26, having 35 ft. 9 in. depth of water on the sill. A junction lock L, Fig. 3, 370 ft. long, with gates 60 ft. wide, connects this basin with the East Dock. The chamber of the lock is 120 ft. wide, so as to pass three or four vessels at the same time. The existing dock accommodation provided by the Marquis of Bute and his Trustees now amounts to

77 acres; and the parliamentary powers recently obtained will enable the Trustees still further to increase this accommodation by 54 acres, to meet the growing requirements of the port.

Lock Gates.—The Gates of the sea lock of the new basin are 80 ft. wide, and are believed to be the largest lock gates hitherto constructed. They are shown in Figs. 6 to 20, Plates 27 to 30, and are of wrought iron, on the buoyant principle, with skin plates, diaphragms, and lattice ribs; and with greenheart heel posts, meeting posts, and sills, as shown in Figs. 11 to 13, Plate 28. Each leaf of these gates weighs 145 tons. They were constructed by Sir Wm. Armstrong and Co., the arrangement of lattice ribs shown in the plan, Fig. 10, Plate 28, being adopted at the suggestion of Sir Wm. Armstrong as affording more convenient access to the interior for examination and repair, and also diminishing the weight in comparison with solid plate ribs. Three solid plate diaphragms are inserted at A, B, and C, Figs. 6 and 7; of which the upper and lower ones, A and C, are made water-tight for giving the required amount of buoyancy to the gate. In order to provide for ballasting the gates at spring tides, pipes are fixed at D D, Figs. 6, 7, and 14, through which the water is allowed to run in and out of the chamber above the upper water-tight diaphragm A, as the tide rises and falls, this diaphragm being 15 ft. below the top of the gate. A manhole tube E, Figs. 6 to 8, affords access from the top of the gate to the water-tight compartment below the diaphragm A whenever there is water above it at spring tides; at other times the three other manholes shown in the plan, Fig. 8, can also be used. The adjustment of the load upon the carrying roller F, Figs. 15 and 16, Plate 29, is effected by the vertical compression bar G bearing on the top of the roller carriage, the upper end of the bar being fixed by cotters at the top of the gate. The anchor plate securing the top of the heel post is shown in Figs. 17 and 18, Plate 30; and the bottom pivot in Figs. 19 and 20.

The gates of the junction lock L, Fig. 3, between the new basin and the east dock, are 60 ft. wide, and are of wrought iron, similar in general design to the gates of the sea lock, but with solid plate ribs in place of lattice ribs; they were constructed by Messrs.

Maudsley Brothers, of the Bute Iron Works, Cardiff. The lock gates, bridges, capstans, and sluices, connected with the new basin, are worked by hydraulic machinery; those at the east and west docks were arranged for hand power, and are still so worked.

The provisions for the examination and repair of vessels entering the port consist of four graving docks, one situated at K, Fig. 3, Plate 25, 220 ft. long, entered from the west dock; the second at M, 400 ft. long, entered from the east dock; both constructed by Messrs. Hill and Sons, on ground leased to them by the Bute Trustees. The third graving dock, 267 ft. long, is outside the entrance of the docks at N, close to the steamboat harbour S, and is the property of Messrs. Gunn and Co. The fourth graving dock, 600 ft. long, with an entrance 60 ft. wide, has been constructed by the Bute Trustees, and is entered from the new basin at R; it will be available for use by the public on payment of dockage rates, as at Liverpool. A gridiron 350 ft. long has also been constructed by the Bute Trustees at G, Fig. 3, on the east side of the channel outside the entrance of the docks.

A low-water pier, Figs. 2 and 3, 1400 ft. long and 34 ft. wide, was constructed in 1868. The pier head is provided with a floating pontoon or landing stage, and the minimum depth of water is 6 ft. at low-water spring tides. A railway is laid along the pier, and also a carriage way; and a vertical lift and 10 ton hydraulic crane are fixed at the pier head, together with suitable waiting rooms and conveniences. Prior to the construction of this pier, all communication with vessels in the roads was cut off for a considerable time at each low water, which caused much inconvenience.

The principal portion of the trade carried on in the Bute Docks is the export of coal and iron, which amounted to $2\frac{3}{4}$ million tons in the year 1873. The import trade of iron ore, timber and general merchandise, amounted in the same year to 630,000 tons. The consequence of the preponderance of export is that ships arrive at the port mostly in ballast; and special provision is required to be made for the discharge and deposit of this ballast.

There are seven steam cranes for this purpose, four of which are capable of discharging 50 tons each per hour. These steam cranes discharge the ballast into railway wagons, which are conveyed a distance of about two miles to spare land where the ballast is deposited. To provide for the safe removal of the vessels from the ballast quay to the loading berth, after the discharge of the ballast, wooden booms weighing from 5 to 15 tons each are now fixed one at each side of the ship, to keep it steady after the ballast has been removed. The growing use of water-ballast for steamers engaged in the coal trade at the present day has greatly expedited the preparation of vessels for receiving their outward cargoes.

The mineral traffic of the west dock is supplied exclusively by the Taff Vale Railway from Merthyr, Dowlais, and the Aberdare and Rhondda Valleys. The traffic to the east dock is supplied jointly by the Taff Vale, the Rhymney, and the Great Western Railway, the last of which is the means of communication with the great coalfield now being opened up in the centre of Glamorganshire in the Ogmore district. The London & North Western and Midland Railways have also access to the docks by their connection with the above railways. A general plan of these several railways communicating with the port of Cardiff is shown in Fig. 1, Plate 23.

A very large extent of siding accommodation is required for working the coal shipping trade, for, owing to the fluctuations of the trade, loaded wagons have to be stored in the sidings at times when the supply exceeds the demand. The extent of sidings provided and maintained by the Bute Trustees in connection with the docks amounts to 16 miles in length, the whole of which is at times fully occupied.

Coal Tips.—The mechanical arrangements for shipping coal at the west and east docks are on the High-level or balance principle, as shown in Plates 31 to 33. But at the new basin the Low-level system has been adopted, with hydraulic tips for elevating and tipping the wagons, as shown in Plates 34 to 36. The number of tips for loading coal at the Bute Docks is as follows:—

15 Balance Tips at the west dock, shown at B B in Fig. 3, Plate 25.
14 „ at the east dock, „ „
5 Hydraulic Tips at the east dock and entrance basin, shown at H H.
1 „ in the entrance channel for loading in the tideway.
8 „ at the new basin.

43 Total number of Tips.

Each tip is capable of shipping 560 tons of coal per day of ten hours; the total shipping capacity of the Bute Docks is therefore equal to nearly 8 million tons of coal per annum. In some instances as much as 200 tons of coals have been shipped per hour at the new hydraulic tips; and it is now not uncommon for a steam collier of 1500 tons to enter the basin at high water of one day, discharge her ballast, receive her outward cargo, and leave at high water the following day, the entire operation having occupied less than 24 hours.

Balance Tips.—The Balance Tips, shown in Figs. 21 to 25, Plates 31 to 33, consist of a suspended cradle or platform A, sliding in vertical guides and supported by balance weights B B connected to it on each side by chains passing over pulleys C C at the top of the framing, upon which are breaks D for controlling the motion of the cradle; the balance weights are sufficient to raise the cradle and empty wagon, but not equal to the load when a full wagon is upon the cradle. The wagons are each discharged from an end door into an inclined shoot E extending over the ship's hatchway and having screens in the bottom for separating the small coal. The wagon is tipped for this purpose by hooking a suspending chain on the tail end, and then lowering the cradle by means of the breaks until the wagon is tipped sufficiently for discharging the coal, as shown in Fig. 21. The break is then released, and the cradle with the empty wagon rises to the top again, and the wagon is run off into a siding; the cradle is then ready to receive another wagon.

In discharging the wagon by this means, a height of 9 ft. is lost by having to lower the cradle for tipping the wagon, as in Fig. 21; and a gradual increase in the size of ships to be loaded rendered it necessary to prevent this loss of height in the tips, in order to raise the shoots to the level required by the higher decks

of the ships. This was effected by raising the tail end of the wagon for tipping it, as shown in Fig. 22, Plate 32, instead of lowering the cradle; the tail end was hauled up by a winch worked by men. This tedious process was subsequently superseded with great advantage by a hydraulic lift, consisting of a simple Armstrong crane cylinder G, Fig. 22, with 9 in. ram and double pulley connected to the tipping chain; and this plan is now in general use in the balance tips at both the west and the east dock. The first balance tips constructed at the west dock received the wagons on the cradle at the level of 18 ft. above the quay; but the continued increase in the size of the ships to be loaded has necessitated raising the railway level and the framing of the tips 3 ft. higher, making the level for the wagons at the west dock 21 ft. above the dock coping or 22 ft. above the water. The coal tips at the east dock were originally constructed at this higher level, and in consequence of further increase in the size of the ships to be loaded the height of the additional tips recently constructed has been further increased 6 ft., making 27 ft. height above the coping.

It is necessary to adjust the level of the shoot to the actual height of each ship, so that no greater height of fall may be given to the coal in any case than is necessary for getting it into the hold, in order to reduce the breakage of the coal as much as possible; and for this purpose the butt end of the shoot E, Figs. 21 and 22, where attached to the frame of the tip is made to slide in vertical grooves, and is supported by chains which can be raised or lowered by a hand winch H, Fig. 24, the greater portion of the weight being counterpoised by a balance weight K, Fig. 24. The point of the shoot is also carried by similar adjustable chains with balance weights L and winch M, so that the inclination as well as the height of the shoot can be changed as desired.

Hydraulic Tips.—When the Great Western Railway came into Cardiff on the low level, crossing below the other railways and with the rails at the level of the quay, it was necessary to provide means of raising coal wagons from that level to a height sufficient for discharging them into ships; and for this purpose the

Armstrong Hydraulic Tips were adopted. The first of these hydraulic tips erected at the Bute Docks was made in 1858 with timber framing; but the later ones are entirely of iron, and this improved construction is shown in Figs. 26 to 29, Plates 34 to 36. The cradle A that carries the wagon is raised by a vertical hydraulic ram B of 12 in. diameter and 20 ft. stroke, and slides in guides at the four corners; upon it the loaded wagon is raised to the level of the shoot E, Fig. 27. The centre portion C of the cradle, with the rails upon which the wagon rests, forms a tipping frame, being pivoted at the front of the cradle; and is tipped with the wagon upon it, as shown dotted in Fig. 27 and full in Fig. 28, by means of a second hydraulic cylinder D below the cradle and attached to it. This cylinder oscillates on trunnions to follow the motion of the tipping frame, receiving its supply of water through one of the trunnions from the hollow ram B of the main centre cylinder. The whole working is conveniently managed by a man standing on a side platform F, Fig. 26, at the top of the framing, with the several hydraulic levers close at hand.

The raising and lowering of the shoot E, Figs. 27 and 28, Plate 35, for adjusting its height and inclination, are effected by simple self-acting means, which entirely dispenses with the hand labour required in the balance tips and obviates the consequent loss of time. Two short arms are made to project from the front of the cradle A, one at each side, under the butt end of the shoot; and when the cradle rises the shoot is by this means carried up with it to any desired level, and is held there by a weighted paul falling into a vertical rack fixed upon the frame on each side of the shoot: or by holding these pauls disengaged from the racks the shoot can be lowered with the cradle to any lower level. The shoot is secured in addition by a safety chain on each side, which is fixed in the new position by a clip G, Fig. 27. The two arms that lift the shoot are balanced so as to hang vertically, and clear of the shoot, when not in use; and when required they are thrown into action by pulling a small chain. The point of the shoot is raised or lowered in a similar manner by means of two chains carried over pulleys at the top of the framing and brought down the

centre of the framing, one at each side, where they are secured to the frame by clips at the desired level. When required to be altered, these chains are put upon strong hooks fixed at the edge of the cradle, and then by lowering or raising the cradle the point of the shoot is raised or lowered as desired, and the chains are pinned again in the new position by the clips.

Anti-Breakage Cranes.—As the South Wales coal is of a brittle character, it is found necessary to take special precautions for reducing the loss by breakage that occurs in discharging the coal wagons into the ships' holds; and for this purpose the Anti-Breakage Crane N, Figs. 21 and 27, Plates 31 and 35, has been applied with great success, and is now in general use. This has a square iron bucket P holding one ton of coal, made hopper-shaped with a hinged flap for discharging at the bottom; it is suspended from an independent light jib crane N, fixed at one side of the tip frame, and having in the hydraulic tips hydraulic lifting and turning motions. In commencing the loading of a ship, this bucket is filled from the shoot, and then lowered to the bottom of the hold, and emptied by pulling up the bolt that secures the flap door: the process being repeated until a conical heap of coal is formed high enough to reach nearly to the hatchway, as shown in the sketches Figs. 30 and 31, Plate 36. The shoot is then allowed to discharge freely, and delivers close down upon the heap, so as to prevent any breakage of the coal by a vertical drop. The point of the shoot is contracted to check the fall of the coal down the incline, so that the shoot is choked up by coal, and the discharge from the point requires a little assistance by hand, and is thus kept under control whilst the bucket is being filled. The whole process is effected with great expedition, the discharge of the bucket in the ship's hold being made self-acting by the bolt that releases the flap door being fastened to a chain, which is fixed on deck and shortened to the required length as the filling proceeds. These cranes are also used with advantage for discharging ballast or ordinary merchandise, and for filling into wagons the small coal that passes through the screens in the shoots on to the ship's deck.

Notwithstanding all these precautions the proportion of slack that is found in the coal when the ships are discharged at the end of the voyage is generally too large to be satisfactory; and the author considers that this is due to the want of care in trimming the coal in the ship's hold, in which process great breakage of coal is caused by the carelessness of the men. This has been practically tested at the Bute Docks by loading a vessel by means of wheelbarrows filled direct from the wagon and lowered into the hold, and then wheeled at once to the far end of the hold so as to avoid any subsequent trimming: the result was that, though some extra cost of loading was incurred, the coal was delivered in such exceptionally good condition, that the extra cost was much more than covered by the reduction in loss from slack.

Comparison of Balance and Hydraulic Tips.—In the comparison between the balance tips and the hydraulic tips, there is not much difference either as to facility and rapidity of shipping coal or as to cost of working, when applied in the case of a fixed water level, as at the East and West Bute Docks, which are constantly kept up to the level of one foot below the coping by the feeder from the river Taff. In the tideway however, outside the docks, the hydraulic tips are in the author's opinion much superior to the balance tips, as they afford the means of a much greater range of working. An objection to the balance tips is the heavy embankment and staging required for bringing in the railways and sidings on the high level, and the large amount of space so occupied; this consideration led the author to adopt the low-level system with the railways and sidings on the quay level, and hydraulic tips, for the new basin just completed and for the future contemplated docks at Cardiff, where space could not be afforded for the embankments and stagings required for balance tips. On the other hand, it has to be noticed that the hydraulic tips have the disadvantage of being liable to a stoppage in the loading of the ships, if anything goes wrong with the machinery or a pressure-pipe or a single cupped-leather gives way. However during the last eight years' working of the hydraulic tips at Cardiff the writer has not experienced any difficulty of the kind;

but in order to ensure this a careful watching has been kept up of the whole of the hydraulic machinery, especially of the cupped-leathers, of which a constant register is kept of every renewal, to ensure the removal of each within a safe time. After considerable experience of the working of both plans, the author considers that the balance of advantages rests with the low-level system. The original balance tips were constructed for wagons with a total weight of 10 tons, being 7 tons load and 3 tons wagon; but in consequence of the gradual increase in size of wagons, the more recent balance tips were constructed for a load one half heavier, or 10 tons load with $4\frac{1}{2}$ tons wagon, making $14\frac{1}{2}$ tons total; and the new hydraulic tips are constructed for lifting a total weight of 20 tons.

Hydraulic Hauling Engine.—The Hydraulic Hauling Engine shown in Plates 37 and 38 has been introduced for the purpose of drawing the wagons on and off the coal tips, in place of horse power, and for turning them on the turntables. It is designed and constructed by Sir Wm. Armstrong and Co., and consists of a hydraulic engine with a pair of double-acting oscillating cylinders A A, working right-angled cranks upon a shaft to which a cupped chain-wheel B can be coupled by a clutch C. The chain by which the wagons are hauled passes over this wheel, into the groove of which it is pressed by a pair of guide rollers D D; and the fall of the chain is piled down upon the floor of the pit E. The entire engine with the chain wheel and guide rollers is fixed on the underside of a cast-iron bedplate F, which is flush with the ground when the machine is in use, as shown in Fig. 32; but it is mounted on trunnions G G, so that it can be turned up when required for examination or repair, as shown in Fig. 33. By this arrangement the size of the pit required for containing the machine, and the cost of foundations, are much reduced. The pressure water is supplied to the engine at one of the bedplate trunnions, and the exhaust water conveyed away from the other. The valve for the admission and exhaust of the water to each oscillating cylinder is placed in one of the trunnions of the cylinder, and is worked by the

oscillation; the valves are arranged so that they can be readily removed for examination or repair. The machine is worked by a single hand-lever H, which throws the clutch C of the chain-wheel into gear, and at the same time turns on the water pressure to the cylinders by opening the stop-valve K, Fig. 34; the lever is held back by a catch in the bedplate when out of action, and the chain-wheel is then free to turn upon the shaft and the chain can be drawn out. For starting the machine, the lever is simply released from the catch, and is then pressed home by a spring J, Fig. 34; but it is controlled by hand by the attendant so as to start the machine gradually, without any sudden snatch upon the hauling chain. This hauling engine has proved very satisfactory and efficient in working; and its advantage in expedition of work and in dispensing with horses is so decided that one is about to be added to each of the hydraulic tips at the new basin.

Portable Hydraulic Crane.—For expeditiously discharging or loading ships with grain or general cargoes, a separate crane for each hatchway is very desirable; but owing to the varying distances between hatchways in different vessels, fixed cranes cannot be adapted to the circumstances; and it occurred to the writer to meet this difficulty, and still utilise the hydraulic power, by employing portable cranes that could be placed in any required position alongside the ships. In Plate 39 is shown a Portable Hydraulic Crane that can be traversed upon a line of railway parallel to the dock wall, and is supplied with water pressure by means of a series of hydrants placed 20 ft. apart along the dock wall, so that by jointed wrought-iron pipes and a union joint the power can be supplied to the cranes within 10 ft. distance in any position. The details were worked out and the crane constructed by Sir Wm. Armstrong and Co.; it is similar in construction to the hydraulic cranes in general use, the lifting cylinder and tackle being placed within the wrought-iron pillar A of the crane, which revolves in the centre of a platform D that is mounted on four carrying wheels travelling on the line of railway. When the crane is in use, the platform is steadied by a screwed resting block B at each corner, and is held down to the rails by clamps C; a cast-iron

counterweight E is fixed to the back of the pillar A, to counterbalance partially the load lifted by the crane, and reduce the strain upon the clamps. The turning machinery is fixed on the platform D, which is cleaded in with wood, and a house is formed at one end for the man working the crane. Two of these cranes, each to lift 46 cwts., and a smaller one to lift 27 cwts., are in use at the Bute Docks, and they have proved very serviceable and satisfactory in work, and are very efficient in discharging a ship quickly by working at both hatchways at the same time.

Motive Power.—The motive power for working the hydraulic machinery at the Bute Docks consists of two pairs of engines with cylinders 16 in. diameter and 20 in. stroke, working direct four force pumps $4\frac{3}{4}$ in. diameter, which supply three accumulators shown at A in Fig. 3, Plate 25; two of these are placed contiguous to the engine house, and are weighted with 70 tons of gravel suspended on rams 17 in. diameter, giving a pressure of 700 lbs. per sq. in.; the third is placed at a distance of three quarters of a mile, at the head of the East Dock, and is weighted with 100 tons of gravel suspended on a ram 20 in. diameter, giving the same pressure of water. The engines are supplied by four boilers, 25 ft. long and 5 ft. 6 in. diameter, three of which are always kept at work, while the fourth can be used in case of accident or when the others require cleaning. Each pair of engines is capable of working up to 40 horse power with a boiler pressure of 60 lbs. per sq. in. The pressure pipes P, Fig. 3, in connection with the various cranes, tips, lock gates, capstans &c., extend upwards of three miles, and vary from 3 in. to 5 in. diameter along the mains, and are constantly under the pressure of 700 lbs. per sq. in.: the whole having been supplied by Sir Wm. Armstrong and Co.

Mr. P. G. B. Westmacott, having been associated with the introduction of hydraulic appliances for shipping coal in that district, mentioned that about 1850 the Glamorganshire Canal Co. offered a large premium for the application of machinery for discharging coal from their barges; and this premium was gained by Sir William Armstrong and resulted in the application of the hydraulic hoists on that canal. The next application was at Swansea, where the box system was introduced by Mr. Brunel on the South Wales Railway for the conveyance of coal to the docks, in order to avoid the breakage of the coal as much as possible. Iron boxes, each containing $2\frac{1}{2}$ tons of coal, were loaded at the collieries, and conveyed on wagons to the hydraulic hoist on the quay. Each box was constructed with double doors at the bottom, and had three chains, one attached to the box itself and the two others to the doors. The wagon being brought under the hoist, each box was lifted off it and lowered through the ship's hatchway until the bottom of the box was close to the ship's bottom or upon the surface of the coal; and the doors being then opened by means of the chains the contents were let out. These hoists were planted on a railway viaduct at a height of 60 feet above high water, and stood upon wooden framings. This system of boxes had gone out with the change from broad to narrow gauge; there is only one of these machines now remaining at Swansea.

The next plan which came into use in that district for shipping coal by hydraulic power was the hydraulic hoist described in the paper; the first of these hoists were erected in 1854 at Newport, where they had been working ever since. At Newport docks the rails were on the low level, parallel to the quay wall, and an endless-chain system worked by hydraulic machinery was tried for bringing the wagons up to the hoists; this failed, and the machines were converted into capstans, which answered admirably. The wear and tear of the ropes however had been so great that they were superseded by chains, which prove durable; and he noticed recently a 5-16ths inch chain which had been in use there four years and a half, and seemed as good as ever; a chain of that size would haul a train of wagons containing a load of about

160 tons along a level on the railways at the docks. There were a great number of the hydraulic hoists at work in the district, at Swansea, Briton Ferry, and other places.

Mr. W. E. Newton considered that, in regard to the shipping of coal, the paper had not at all exaggerated the importance of preventing the breakage of the coal in that district, where a large proportion of the coal was of a very tender kind; and it seemed rather surprising that more had not been done in the introduction of improvements for the express purpose of preventing this very important waste. A plan had recently been introduced by Mr. John Price of Sunderland, and was being carried out in a ship now building there, by which the coal was properly trimmed in the ship's hold without any handling; instead of first building up a conical heap of coal for the shoot to deliver upon, as shown in the diagrams, Plate 36, a distributing cone or inverted hopper is constructed of wrought iron, and is suspended underneath the hatchway, so that the coal delivered upon it from the shoot is conducted to the sides of the hold, and then rolls down towards the centre, thereby depositing itself in the form of an inverted cone. In order to provide for properly depositing the stream of coal lengthways along the ship's hold, instead of in a single spot, moveable leaves are hinged to the sides and ends of the distributing cone, and their inclination is adjusted by chains, so as to let the coal slide down them easily and without shock. By that means the coal is very carefully loaded into the ship, and with as little breakage he thought as could possibly be. In another arrangement a distributing cone which is not a fixture in the hatchway is mounted upon a trolly running upon longitudinal bearings, so that it could be moved lengthways along the hatchway while the coal is descending, and can be shifted from one hatchway to another; and where the masts prevented its further passage, an inclined leaf is attached to it at each end, for spreading the coal endways in the ship's hold, so as to deposit the coal in all parts of the hold by simply letting it slide down the inclines from the distributing cone.

Mr. R. Price Williams had been struck with the reference made in the paper to the excessive breakage of the coal in

shipping, and the ingenious provision adopted for diminishing the breakage. Some years ago, when he was connected with the Great Northern Railway, a plan was proposed by Mr. Plimsoll for preventing the excessive breakage that took place in the ordinary mode of loading coal through hoppers, by the employment of a series of inclined planes, arranged in reverse directions where necessary, so that the coal might always slide and never fall. The plan having been worked out by himself from Mr. Plimsoll's design had been ever since in practical use very successfully at the Great Northern Railway and other principal coal depôts; the saving thereby effected amounted to 6*d.* per ton with ordinary coal, and would be still greater with the very friable Welsh coal. It seemed to him that the operation of building up a preliminary heap of coal in a ship's hold by means of a bucket, as described in the paper, would be a very slow process; and he suggested that the whole of the work might be done by a series of zigzag inclines, by which the coal might be entirely deposited in any part of the hold without ever having any fall. He thought there was room for the exercise of further ingenuity in connection with this question, and that it was one which engineers would find well worthy of their attention.

Mr. E. A. Cowper considered they were much indebted to Mr. McConnochie for bringing out so many points of detail in his paper. The arrangement described for keeping a vessel upright after the ballast had been taken out, by attaching two booms at the sides, was a very simple and ingenious one; a ship that was a good sailer when in ballast might not be able to keep upright when the ballast was discharged, and this mode of steadying would therefore be of great use in such cases; he enquired in what way the booms were attached to the sides of the ship.

In reference to the two plans in use for tipping the coal into the vessels, he enquired whether there was found to be any advantage in point of time with the high-level system and the balance tips. If there were no saving in time, he thought it was evident that the hydraulic tip was the best; and there was no occasion to anticipate any trouble with regard to packing in the use of hydraulic

machinery. It was well known that with leather packings hydraulic machinery could be kept in perfect order, provided there were constant supervision and an examination of the packings every three or six months, so as not to go on working until it became necessary to stop because a leather was worn out. If however the high-level system gave any advantage in time, the balance tip might be the best to use in conjunction with it; otherwise he considered it much better to have the railway lines all on the level of the quay, and to run the trucks upon the hoist and elevate and tip them at once. There was no difficulty in doing this with the hydraulic hoist; and the quantity of coal shipped by one of these hoists, 200 tons per hour, was very satisfactory, and was probably quite fast enough. The water pressure of 700 lbs. per square inch for working the hydraulic machinery seemed rather higher than he thought was usual in such cases. The hydraulic hauling engine appeared to be very conveniently arranged for turning it up on the foundation plate so as to expose the whole to view. There was a very general feeling now to make parts of machinery capable of ready examination, and for this purpose to resort to such expedients as this, namely the turning of a part on centres, so as to retain the accurate adjustment of the part when turned back into its place. In the "saw gin" for taking cotton off the seed, the grids turned back on centres for the purpose of examination or adjustment; and in Heilmann's cotton combing machine, as made by Messrs. Platt, several separate parts could be turned back on centres in an admirable manner, for adjustment and examination.

In reference to the difficulty experienced from breakage in shipping steam coal, which was so tender and so valuable, he mentioned that about twenty-five years ago, before long hatchways were introduced, in consequence of the very considerable breakage that occurred in shipping coal at Birkenhead, a plan had been devised by himself in conjunction with Mr. William Laird for shipping the coal with less breakage, by delivering it from the shoot into a vertical telescopic tube which was filled up with coal; this tube could be inclined or moved from side to side or from end

to end of the hold, so far as the hatchways would allow, and could be shortened or lengthened as required, so as to deliver the coal quietly into all parts of the hold that could be reached. He had also devised an arrangement for trimming coal and other materials, such as casks, because when one layer of casks had been stowed it was not easy to roll others over them, nor to trim coal except by shovelling it. Advantage was therefore taken of the deck beams to construct a hanging railway underneath them; on this ran a small hanger or runner, fitted with chains and coupling hooks that could be shortened or lengthened by a hand lever or handle, and in trimming casks a man could thus run them along over the heap below into any part of the hold, so long as there was any head room left at all. This plan was largely in use at the present time in the royal navy for trimming coals and removing cinders.

Mr. Jeremiah Head said that, instead of making special arrangements for preventing the disintegration of coal, his firm happened at that moment to be occupied in putting up machinery for pounding it up as fine as possible. In the President's address it had been stated that the total annual quantity of coal raised in this country was about 120 million tons; of this amount it might safely be assumed that about one third was used for household purposes, one third for metallurgical processes, and the remaining third for the generation of steam power. He believed before long it would be proved that the two thirds required for steam and metallurgical purposes could be better and more economically used in a fine than in a massive condition; for household purposes it would probably still be necessary to use large coal. Although therefore the appliances described in the paper for tipping coal without disintegration were valuable under present conditions, he thought the truer direction for the useful exercise of mechanical ingenuity was to devise means of utilising, rather than of avoiding the production of, small coal.

With respect to the ballast discharged from ships arriving at Cardiff, which appeared to be conveyed at present a distance of two miles by railway and there tipped, there appeared from the plan

shown of the port of Cardiff (Plate 24) to be an extensive foreshore between high and low water-mark, which must be a disadvantage rather than otherwise, being sometimes covered with water and sometimes not; if the ballast were tipped there, the land so formed would be of great value. On the Tyne the ballast discharged from ships had for ages past been deposited at considerable expense in great hills on either side the river below Newcastle; these were very unsightly, and some of them had had to be removed at great cost, that certain improvements might be made. At Cardiff therefore, where there was so extensive a foreshore, he wished to know whether there was any real difficulty in utilising it for tipping ballast, thus converting waste into useful land.

In reference to the portable hydraulic crane shown in Plate 39, he thought it was worthy of remark that at Middlesbrough, where a dock had been constructed which was provided with steam cranes, the cranes did not run upon the same line of railway as the trucks, but on a line of wider gauge, straddling over the trucks. By that arrangement the whole of the lifting machinery was kept up overhead, out of the way of the trucks, which passed underneath; and this appeared to him a great practical convenience in working, which could not be obtained with the construction of crane shown in the drawing.

Mr. R. H. Tweddell thought that the highly satisfactory results given in the paper with regard to the working of the hydraulic machinery employed at the Bute docks would serve to remove any doubts hitherto entertained respecting the pressure that could be economically and advantageously used, and the durability of the packing employed. The packing had been an objection often brought against the use of hydraulic machinery; but even the leather packings referred to in the paper were stated to have given no trouble during eight years. But hemp packing he believed was now being used in Sir Wm. Armstrong's hydraulic machines to a much greater extent than leather; and having himself used leather both for the more ordinary pressures and for much higher ones also, he had found hemp packing last better

also for pressures of 1500 or 2000 lbs. per sq. in., and had used it up to even 2300 lbs. without any trouble, both as inside packing for pistons and outside packing for rams.

With reference to the hydraulic hauling engine described in the paper, he enquired whether the drawing out of the chain after it had been hauled in was done by hand. He did not see any advantage in that construction of engine over an ordinary hydraulic capstan working with ropes.

The experience obtained in the working of the hydraulic machinery at the Bute docks having been on such a large scale, he should be very glad if the author of the paper could give any information with reference to the loss by friction in transmission of power over such great distances by water pressure, as compared with other modes of transmission; any such particulars would be of great value.

Mr. Benjamin Walker enquired whether any particulars had been ascertained of the actual consumption of coal required to raise such great weights of material as were dealt with in loading and unloading ships by means of the hydraulic machinery at the Bute docks, where the very extensive application of hydraulic power afforded exceptional opportunities for obtaining such information. So much had been said in the President's address about the saving of coal, that every engineer would be desirous of finding out how to economise coal as much as possible; and if any information could be given as to how much coal was actually used, and how much of this was wasted, in the operation of lifting by hydraulic pressure, it would be very useful. It was known that there was a waste of coal in the process, and what was wanted was to obtain some exact information.

With regard to the question of using leather or hemp for packing, leather was considered by some to be far better than hemp, and with clean water and well-bored cylinders it would last a long time. He knew of leathers that had been at work more than two years under a pressure of 750 lbs. per sq. in.; but if used with dirty water, leathers would soon be worn out, and under

such circumstances hemp packing was better. With clean water he thought there was nothing equal to leather, and it was attended with less friction than hemp packing. Having had to make a great number of hydraulic lifts to be worked by the waterworks pressure of only 70 lbs., he had fitted them all with leathers; hemp packing had been tried in some of them, but they could not be made to work with it on account of the friction being so much greater. With so low a pressure as 70 lbs. it was necessary to have the friction of the rubbing surfaces very small; and the friction from the leather being found to be far less than from the hemp packing, the difference was a matter of great importance under such circumstances.

Mr. S. C. Homersham said, with regard to the comparative advantages of leather and hemp packing, from his own experience with clean water he should use neither, but should employ metallic packing, which he considered far superior to either leather or hemp. He had had pumps working for some years with a pressure of 200 to 220 feet head of water and all the packings were metallic; they worked exceedingly well, and were perfectly water-tight, not a single leakage having occurred. These pumps having been made for him by Mr. Walker's firm, he was surprised his attention had not been turned to the use of metallic packing for clean water; he was quite satisfied that, besides obviating all loss from leakage, metallic packing worked with far less friction than occurred with either leather or hemp.

The President enquired what had been Mr. Walker's experience with regard to metallic packing as applied to hydraulic machinery; and why metallic packing should not be used with a heavy pressure. Upon the friction of cupped-leathers of various sizes a series of very valuable experiments had been made by Mr. Hick, which showed some curious results.

Mr. Benjamin Walker replied that he had found metallic packing required everything about it to be perfectly clean and managed with great care. In the common hydraulic cranes, such as were used in foundries and for Bessemer hydraulic machinery, that cleanliness and care could not be had; and it was necessary to submit to the

soft packing and dirty water, because the cleanliness necessary for the metallic packing could not be secured. He should prefer always to employ the metallic packing, as the best construction; but under certain circumstances the use of imperfect appliances must be submitted to.

Mr. T. R. Crampton considered that if more attention were paid to pulverising coal and burning it in a powdered state it would be a profitable and efficient step towards carrying out the principle of economy of coal, which had been so strongly urged in the President's address; and there was more to be done yet he believed in pulverising the coal and utilising it in that state than was commonly supposed at present. Having himself worked at this subject for seven years past, he had found by practical trials that in the case of steam boilers the use of powdered coal saved one fifth of the extent of heating surface otherwise required for generating a given quantity of steam. The reason was that the relative quantities of air and fuel could be regulated exactly to the proper proportion, so that every particle of carbon and hydrogen could be utilised without waste; and the result was that the temperature was maintained with scarcely any change. In one experiment, for instance, with a boiler having 1500 square feet of heating surface, the quantity of air admitted being exactly in correct theoretical proportion to the quantity of powdered coal supplied, the temperature in the smokebox during twenty-four hours did not vary more than 20° Fahr., ranging between 380° and 400°; and from later experience the temperature could now at any time be maintained in such cases with a variation of only 10°. By preserving the proper proportions of air and coal, smoke was rendered impossible; and the value of such a result was well known. In those experiments the evaporative duty realised was 11 lbs. of water per lb. of coal. The importance of preserving a uniform temperature was of course very great in preventing the destruction of boilers by the alternate contraction and expansion consequent upon the opening of the furnace doors; and it was well known that the loss of heat from this cause was great. Under the ordinary

system it was impossible to regulate the admission of the air within 50 per cent. of the proper quantity; but with the pulverised coal the temperature was kept uniform from first to last, and the destructive action upon the boilers from variations in temperature was avoided.

It was considered fortunate if with an ordinary coal fire in a forge a good welding heat could be maintained; and in a reverberatory furnace soft steel could not be melted, there being no power of regulating the quantity of air and of carbon continuously, and consequently the temperature was always varying. But with the pulverised coal the combustion could be regulated to such a nicety that in a furnace of 9 feet diameter four 60 lbs. pots of pure wrought iron had been melted in four hours and run into ingots. This was half an hour less time, as shown by an experiment made to ascertain this, than was required for the same purpose in the Siemens regenerative gas furnace, in which the gas and air were heated up by the regenerators to a temperature of about 2000° before entering the furnace: although perhaps the Siemens furnace could do it in the same time. Thus with common refuse coal and with cold air, simply using these two substances at the temperature of the atmosphere and dispensing altogether with the heat derived from regenerators, he had in the experiment succeeded in a shorter time in obtaining a temperature sufficient to melt wrought iron, which was the highest temperature used in the arts. The reason was that the combustion of common refuse coal with cold air, when mixed in exactly the proper proportions, produced a temperature of say 4000°, which was maintained practically uniform by simply preserving the correct proportions of coal and air, as was readily done by the employment of pulverised coal; and the melting temperature of wrought iron being (say for example) 3500°, there was thus a continuous and uniform excess available of 500° above the melting point. In the experiment with the regenerative gas furnace there was more or less variation in the temperature, and the consumption of coal was greater than with the pulverised coal and the cold air. He considered therefore the plan was one of grave importance, and was destined to be useful to a great extent in the arts.

Mr. McConnochie replied, in reference to trimming the coal in the ship's hold, that he had tried various methods, including inclined plane arrangements such as had been named; but he had found that the breakage was mainly caused, not by the falling of the coal upon the top of the mass below, but by the crushing in passing along the shoots, and in trimming it into position between the decks. For trimming in large sailing vessels, where there were so many obstructions between the decks, he believed the work could be done as cheaply by the barrow system, wheeling the coal into position in the ship, and levelling it at every 3 feet height by laying planks for wheeling the barrows at that level. But in a steamer with long hatchways the trimming could be done more easily and cheaply by the use of the inclined shoots, though the amount of breakage was then greater than with the barrows.

The arrangement for keeping the vessels steady and upright when the ballast was out, by attaching booms at the sides, originated with Mr. T. E. Harrison, who had it in use on the Tyne. The booms had eyebolts through them, for hooking them on to a block and tackle, by means of which they were hauled up tight against the ship's sides, so as to prevent her from leaning over to either side.

With regard to utilising the ballast by depositing it upon the foreshore, he should only be too glad to cover the foreshore with it as soon as permitted to do so. In 1863 a large and progressive scheme had been brought forward by the Bute Trustees, in which the intention was to tip ballast round along the foreshore, leaving a space within for new docks to be constructed when required. Unfortunately only a small part of that scheme had at present been sanctioned; a portion of it however had already been carried out, the new basin just completed and the embankment being upon the foreshore, and he hoped sometime to see the entire foreshore covered with docks.

The portable hydraulic crane described in the paper had been designed so that it could run either along the line of rails on the level of the quay, or on a platform raised above the quay, so as to

get headway above the ship's deck with varying heights of the water in the docks.

The hydraulic hauling engine was simply a modification of the capstan engines already used at the docks. The chain was drawn out again by hand after it had been hauled in, the chain drum being then thrown out of gear by shifting the clutch, so as to leave it at liberty to run backwards as the chain was drawn out.

With regard to the cost of shipping the coal per ton by the hydraulic tips, and the consumption of coal for the purpose, he would ascertain the particulars and supply them.*

With respect to the relative advantages of the high and the low level system for shipping coal, the former had no doubt been adopted at the old docks because of the railways being there at the high level for passing over the streets. But at the new works, where there was no room for embankments, he had introduced the hydraulic mode of shipping the coal. The hydraulic cranes were also attended with great facilities; for when not at work shipping coal they could be used for discharging ballast, iron ore, and other cargoes.

The PRESIDENT said they were very grateful to Mr. McConnochie for having brought a subject of such importance before the meeting, and he was sure all would appreciate the value of the information furnished in the paper; they would have the gratification that afternoon of visiting the docks, and of witnessing the actual working of the machinery. He moved a vote of thanks to Mr. McConnochie, which was passed.

The following paper was then read :—

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* The amount of coal consumed for shipping one ton of coal by the hydraulic tips is found to be 1·72 lbs.; and the cost of shipping and weighing the coal is 2¼*d.* per ton, including use of railways and locomotives, labour in shipping, interest on cost of tip, and all charges.

ON THE PUMPING MACHINERY FOR EMPTYING THE DRY DOCKS AT CHATHAM AND AT RIO DE JANEIRO.

By Mr. GEORGE B. RENNIE, of London.

The new Dry Docks at Chatham and the works in connection with them, for the repairs of the ships of the Royal Navy, adjoin the old Dockyard, which is situated ten miles up the river Medway, near the mouth of the Thames, as shown by the light shaded area in the accompanying general plan, Fig. 1, Plate 40, and dates its existence from the time of Queen Elizabeth, shortly before the Spanish Armada in 1588; it was improved in the reigns of James I and Charles I, and the first dry dock is said to have been constructed there in the latter period. In 1667 the celebrated Dutch Admiral De Ruyter sailed up the Medway, and after destroying several of the largest ships of the English navy was stopped at Upnor Castle, just before reaching Chatham Dockyard. Subsequently the dockyard was enlarged and improved at various times, until it extended for more than three quarters of a mile along the south bank of the river, and covered an area of about 80 acres. It contained four small dry docks of wood up to the year 1820, when a fifth of larger size was constructed by the late John Rennie, of granite, and more suitable for the largest class of vessels then in the navy.

The breadth of the Medway opposite the dockyard is only 1250 ft. at high water, and 950 ft. at low water, with a depth of 14 to 20 ft. at low water of spring tides; and this depth is scarcely increased for a distance of two miles down the river to Gillingham Reach. In a report made to the Admiralty by John Rennie in 1814 the disadvantages of the position of a dockyard so far up a river as Chatham, or as Woolwich and

Deptford, were clearly pointed out; but as it was determined to retain these dockyards, it was suggested in this report that the best mode of remedying the evils of shallow water and difficult navigation would be by making a direct communication with Gillingham Reach, thus saving the round of two miles in shallow water; "for the great detention and hazard of bringing ships up the Medway lies between Gillingham Reach and the dockyard." A more detailed report was made some years later, with estimates for the required works; but the proposal fell through, and the system of patching and altering the old dockyard and enlarging the old dry docks went on from time to time, until eventually it was determined to enlarge the dockyard considerably, and to construct new basins and dry docks on the adjoining mud flats known as St. Mary's Islands, covering the area shaded dark in the plan, Fig. 1, and to make two entrances, one near the old dockyard and the other at Gillingham Reach.

The plans for the new works were prepared about 1860 by the Admiralty Director of Works, Colonel Green; but these were considerably modified by his successor, Colonel (now Sir Andrew) Clark. The plan finally adopted and now in course of execution, as shown in the general plan, Fig. 1, comprises three basins; first the Repairing Basin of about 21½ acres, with one entrance into the river near the dockyard, and the other end communicating with the second basin of about 20 acres, called the Factory Basin, which is also in connection beyond with the third or Fitting-out Basin of about 33 acres, with an outlet from this into Gillingham Reach. Thus after a lapse of some sixty years the proposal of John Rennie is now being carried out, so far as the main point is concerned of placing the dockyard in direct communication with Gillingham Reach, though his plan for doing this has been modified.

On the south side of the Repairing Basin four large Dry Docks have been constructed of granite, as shown at D in Fig. 1, each 468 ft. length by 108 ft. breadth on the ground line, with a total depth of 41½ ft. These works have been constructed under the superintendence of Lieut.-Colonel Pasley, R.E., assisted

by Mr. Bernays. At present only the Repairing Basin and the Dry Docks are in use; the Factory Basin is nearly completed, and the Fitting-out Basin is in course of construction. The principal part of the labour is done by convicts, who are now employed in excavating the Fitting-out Basin. At the Gillingham Reach entrance there will be two locks, in order to give facility for passing ships into and out of the basin simultaneously at most periods of the tide, without waiting for high water.

In 1869 plans and estimates were submitted to the Admiralty by the writer's firm, for the Pumping Machinery required for emptying the two graving or dry docks then in course of construction, and to be available also for the two other docks to be afterwards constructed. These plans were eventually adopted at the recommendation of the Committee specially appointed to examine the whole question; and the work has been carried out accordingly by the writer's firm. The following conditions were required to be fulfilled in the design for the pumps. They were to be capable of removing the water from the two docks simultaneously in four hours, pumping into the basin and without discharging into the river, the water in the docks and basin standing at 27 ft. above the sills of the dock entrances at the commencement of the pumping. The pumps were also required to raise water from one foot below the bottom of the dock culvert, and discharge into the basin; or to pump from the river into the basin direct, in order to raise the level of the water in the basin when wanted. It was also considered desirable that in emptying the docks the water should be lowered as rapidly as possible to the level of the "broad altar" course, shown in the transverse section of the dock in Fig. 4, Plate 42, this depth being 15 ft. below the top or 27 ft. water level, and estimated to contain about 18,000 tons of water. The remaining depth from this point to the floor or bottom of the dock is $15\frac{1}{2}$ ft., containing about 12,000 tons of water; so that the total quantity of water to be pumped out in four hours was 60,000 tons, the lift increasing from zero to $30\frac{1}{2}$ ft.

The condition of discharging the water rapidly from the top or 27 ft. level down to the broad altar course was considered to be best met by the adoption of two centrifugal pumps, as the maximum lift would be only 15 ft., and that class of pump is found to be peculiarly adapted for the work of discharging large volumes of water at low lifts. But the form of pump and size of suction pipes required for discharging a large volume of water with a low lift are very different from those required for discharging a small volume with a high lift. This has been shown in the experiments made on centrifugal pumps, such as those for emptying the dry docks at Portsmouth, where at 12 ft. lift the useful effect is 33 per cent., and at 19 ft. lift only 20 per cent.; and it would consequently be very small at 30 ft. lift.

With respect therefore to the lower part of the dock, containing a smaller quantity of water, with a lift varying from 15 ft. to $30\frac{1}{2}$ ft., it was considered that the size, form, and velocity of pumps suitable for the upper portion would be ill adapted for the lower portion, if each pump were to draw and discharge independently, as in the upper portion. It was also desirable to arrange so as to have as little variation as possible in the indicated horse power of the engines throughout the work, as well as in the speed of the engines and pumps. These requirements have been met by having recourse to dividing the lift for the lower portion into two parts, by placing the two pumps at different levels, each pump lifting the water through only half the total height, so that neither of them has to discharge against a greater head of water than about 15 ft.

This arrangement renders it necessary for each pump to be placed in a separate well, with separate suction and discharge culverts, but with a communication between the two wells above the discharge of the lower pump into the suction of the upper pump; and with the means of opening or closing this communication at pleasure by a sluice or penstock. The culvert from the docks to the pump suction is 7 ft. diameter, and about 1050 ft. length, as shown at C C in the section and plan, Figs. 2 and 3, Plate 41, branching just outside the pumping-engine house into two culverts A A, Fig. 6, each 7 ft. high by 3 ft. wide; a sluice is fixed in the

main culvert at the junction, as well as an independent sluice in each branch culvert. The pump wells B B are $11\frac{1}{2}$ ft. diameter, with a total depth of $55\frac{1}{2}$ ft., and are constructed in brick, with granite copings and foundations.

The centrifugal pumps and wells are shown in the section and plan, Figs. 5 and 6, Plates 43 and 44. The pumps E E work horizontally upon vertical shafts F, which have bevel wheels 5 ft. 8 in. diameter fixed on their upper ends, driven by 6 ft. wheels upon a horizontal shaft G. The pumps are carried by collars on the shafts and are keyed upon them; the pumps and shafts are held central by girders fixed across the wells and stayed by short girders at right angles. The lower bearings of the shafts are cased with gunmetal, and work in lignum-vitæ bushes without any end bearings, as shown at H in Fig. 7; and the bearings at the upper ends of the shafts are formed of a series of collars working in gunmetal, as shown at I in Fig. 5, which carry the weight of the pumps and shafts and of the column of water in the centre opening of the pump. By means of screws the level of the pumps can be adjusted so as to give a minimum clearance between the rotating part of the pumps and the fixed part, with the least loss from clearance and the least amount of friction.

The form and arrangement for working the pumps are the same as in the large centrifugal pump made by the writer's firm for H.M. Dockyard at Keyham, but with a larger proportion in the size of the suction pipe to the size of the pump. The pumps are $8\frac{1}{2}$ ft. diameter, and the suction pipes $4\frac{1}{4}$ ft., increasing to 6 ft. diameter at the rose end. The pumps are of cast iron, and of a form that has been adopted by the writer for some time, as shown in Figs. 7 and 8, Plate 45, as he considered and has since found by experiment that the ordinary form of centrifugal pumps with the outflow abruptly at right angles or nearly so to the inflow causes a considerable loss in the delivery of the water. For the purpose of testing this point he had two small model pumps accurately made, as shown half full size in Fig. 9, Plate 46, exactly alike in size, and in number and form of arms, but one with the flow at

right angles, and the other in a curved form as in the Chatham pumps. The experimental pumps were $5\frac{7}{8}$ in. diameter, and the suction pipes $3\frac{1}{4}$ in. expanding to 5 in. diameter at the suction end; the discharge well was $8\frac{1}{2}$ in. diameter. Three experiments were made with each pump, and the time required to fill a tank containing 104·8 cub. ft. was ascertained; the actual lift between the suction water level and the discharge was 8 ft. 3 in.; and the velocity of the pump was kept practically the same throughout all the trials, by means of a pair of cone pulleys. The mean result was found to be that the pump with right-angled flow took an average of 4 min. 48 sec. to fill the tank, and the one with curved flow filled it in 3 min. 52 sec. It is quite possible that much of this difference is due to the high velocity of the water through so small an orifice, the velocity being as much as 380 ft. per min. in the pump with flow at right angles, and although increased in the curved pump to 470 ft. there was an advantage of nearly 20 per cent. in the curved form; but on a larger scale of pump, where the area of orifice is in a much larger proportion to the quantity of water passing through it, the difference would be less marked. At all velocities however some difference would no doubt be shown, as in the case of water passing through different curved bends in pipes.

Having thus ascertained the best form for the pump as regards the vertical section, several experiments were made by the writer as to the number of the arms and their best form in the horizontal section. Three different lifts of 8 ft. 7 in., 14 ft. 2 in., and 30 ft. 4 in. were tried, and indicator diagrams were taken from a small portable engine that worked the pump, and the revolutions of both engine and pump were recorded by a counter. The result was found to be that at all heights the percentage of duty was the greatest when the arms had a curve formed by the resultants of the circumferential velocity at any point and the radial velocity of the water at that point. This curve was consequently adopted for the arms of the Chatham pumps, as shown in the sectional plan, Fig. 8, Plate 45; and it has a close resemblance to the curve advocated by the late Mr. Appold.

The operation of emptying the docks is performed as follows. At the commencement of the pumping, the water standing at the same level in the dock as in the basin, namely 27 ft. above the sill and $30\frac{1}{2}$ ft. above the floor of the dock, the sluice K between the two pump wells is closed, as shown in Fig. 5, Plate 43, and each pump has then a separate suction from the main culvert of the docks, and discharges independently into the basin; but both pumps are driven at the same velocity by the engine and first motion shaft. This continues until the water is lowered the first half depth of 15 ft. down to the broad altar level; the suction of the upper pump from the main culvert C is then closed by the sluice L, Fig. 6, and the sluice K between the two wells is opened, so that the lower pump drawing from the main culvert discharges into the suction of the upper pump, which in its turn discharges into the basin. Thus although the total lift for pumping out the dock increases from zero up to $30\frac{1}{2}$ ft., each pump can be proportioned as regards both size and velocity for a lift increasing from zero up to only about 15 ft.

With this arrrangement the average discharge per minute for each pump, as the water falls through successive depths of 5 ft. from the highest level, was estimated to be as follows :—

1st 5 ft.,	pumps making about	70	revs. per min.	discharge each	245	tons per min.
2nd 5 ft.,	,,	80	,,	,,	206	,,
3rd 5 ft.,	,,	94	,,	,,	147	,,

The total quantities of water to be discharged for emptying each dock through the successive 5 ft. depths are about as follows :—

1st 5 ft.,	6,300	tons, occupying	26 min.
2nd 5 ft.,	5,980	,, ,,	29 ,,
3rd 5 ft.,	5,720	,, ,,	39 ,,
Total	18,000	tons, occupying	94 min.

Consequently the docks would be emptied the 15 ft. depth down to the broad altar level in less than $1\frac{3}{4}$ hours, when the two docks are being pumped out together by the pair of pumps.

The quantities of water to be discharged for emptying the lower half of each dock through successive 5 ft. depths were estimated to be as follows :—

1st 5 ft.,	4,600 tons,	occupying	38 min.
2nd 5 ft.,	4,200 ..	..	41 ,.
3rd 5 ft.,	3,200 ,.	,,	44 ,,
Total	12,000 tons,	occupying	123 min.

The discharge of the two pumps together through this lower portion was estimated to be equal to the discharge of each of them separately through the upper portion, making the time about $2\frac{1}{4}$ hours for emptying the lower half of the two docks from the broad altar level to the bottom of the docks. The total time estimated for emptying the two docks was thus 4 hours.

The following are the results of the actual working, in pumping out No. 4 Dock shown in the general plan, Fig. 3, Plate 41; this dock, as well as No. 3, is somewhat larger than the size upon which the estimate was made, containing 20,000 instead of 18,000 tons of water in the upper half, and 13,830 instead of 12,000 tons in the lower half. The trial was made on 4th March last, and the pumps were started at 12.34 p.m. and emptied the water down to the broad altar level by 1.19 p.m., being 45 min. pumping. The change of sluices was then made for pumping out the lower half, causing a delay of 5 min., and the pumping was completed at 2.42 p.m., being 78 min. pumping for the lower half, and a total time of 2 hours 8 min. for the whole work. This exceeded by 8 min. the estimated time of 2 hours for one dock or 4 hours for two docks; but by a little increase of steam pressure and a consequent increase in the speed of the pumps the time was brought within the estimate, notwithstanding the increase in size of dock.

This is shown in a further trial on 10th March, when the pumps were started at 12.55 p.m., and emptied the water out of the upper half of the dock down to the broad altar level at 1.34 p.m., being 39 min. pumping; and then after a stoppage of 1 min. for the change of the sluices the pumping was completed at 2.35 p.m., being 60 min. pumping for the lower half, and a total time of 1 hour 40 min. for the whole work, or 20 min. less than the 2 hours allowed. The mean Ind. H. P. was 1019, the steam pressure 52 lbs., and the

total revolutions 9724, or $97\frac{1}{4}$ per min. In the previous trial the mean Ind. H. P. was 820, the steam pressure 42 lbs., and the revolutions 86 per min. during the first portion, the speed being afterwards increased to 88 revolutions. The water level of the basin rose 15 in. during the time of emptying the one dock; and a considerable obstruction to the flow of water from the dock was caused by the keel blocks having come adrift and floated over the suction culverts.

During the first 30 min. in the second trial the two pumps were throwing more than 490 tons or nearly 18,000 cub. ft. per min., with a velocity of flow of about 625 ft. per min. through the suction pipes of the pumps and 468 ft. per min. through the main culvert. These speeds for the flow of the water are however too great to get a very economical result, considering the great length of the culvert, and the sharp bends and passages at the heads of the docks and in the discharge culvert, which latter has also the disadvantage of being $10\frac{1}{2}$ ft. below the level of the water in the basin. The result obtained was however as much as 47 per cent. useful effect in the trial, when pumping with a total lift of $26\frac{1}{2}$ ft. These trials were made solely to test the working of the engines and pumps, and to ascertain the shortest possible time required for emptying the dock; but when the dock has to be emptied for the purpose of docking a large ship, nearly one third of the total quantity of water is displaced by the ship, and from the time required for fixing the shores and from other causes there will be no necessity for the use of so great an amount of engine power or speed of pumps and velocity of water through the culverts. The result with the Chatham engines at $26\frac{1}{2}$ ft. total lift on the double-lift system compared favourably with that at Portsmouth with 19 ft. single lift.

On 13th July a further trial was made by pumping out the two docks Nos. 3 and 4 at the same time, under the superintendence of Mr. Eames, the Engineer-in-Chief of the dockyard. The time of emptying the two docks down to the broad altar level was 1 hour 24 min., with an average of $85\frac{1}{3}$ rev. of the engines per min., discharging 40,000 tons of water at a height varying from 1 ft. to 17 ft. 7 in.

total lift. From the broad altar level down to the floors of the docks the time was 2 hours 11 min. 20 sec., discharging 27,660 tons at a height or total lift varying from 17 ft. 3 in. to 34 ft., with an average of 89 rev. of the engines per min.

The engines for driving the centrifugal pumps at Chatham dockyard were originally intended to be an old pair of marine non-condensing trunk engines as used on board H.M.S. "Forth;" but a compound condensing engine was adopted on the writer's recommendation as the main working engine, the old pair of marine engines being fitted as a reserve engine in case of necessity. The compound engine is of the overhead marine type, with two cylinders 43 and 75 in. diameter and $2\frac{3}{4}$ ft. stroke, adapted to make about 96 revolutions per minute, and to indicate from 800 to 1000 Ind. H. P. The high-pressure cylinder has a variable expansion valve; the engine has a surface condenser with vertical tubes, the condensing water being circulated outside the tubes by a centrifugal pump driven by a small independent engine.

The boilers are Cornish double-flued, seven in number, including one spare boiler; they are $6\frac{1}{2}$ ft. diameter and 28 ft. length, working at 50 to 60 lbs. pressure. Two similar boilers are added for supplying the large hydraulic engine for working the sluices and capstans. The flues of the nine boilers have a total area of 44 sq. ft. at the entrance of the chimney, and the chimney has a total flue height of 150 ft. The pumping machinery, consisting altogether of two main engines and pumps, a drainage engine with pumps, and the hydraulic engine with pumps and accumulator, is contained in a handsome building, 51 ft. wide by 180 ft. long, surrounded by an arcade, and having a light iron roof over the boilers, and over the engines a large cast-iron tank of 13,000 cub. ft. capacity, which serves for the fresh-water supply to the dockyard.

The basins and dry docks are provided with hydraulic capstans for warping and other purposes. The hydraulic power for opening and shutting the different sluices and working the capstans is obtained by means of a horizontal steam engine with a cylinder

21 in. diameter and 2 ft. stroke, working two pumps $5\frac{1}{16}$ in. diameter, which supply an accumulator loaded to a working pressure of 700 lbs. per sq. in. This power is estimated to work eight hydraulic capstans hauling 10 tons each at 18 ft. per min. or 5 tons each at 36 ft. per min., as well as four sluices at the same time.

The Sluices with the exception of two are single-faced, of cast iron with gunmetal faces, as shown in Figs. 10 and 11, Plate 46. The hydraulic cylinders by which the sluices are worked are proportioned so that any sluice may be raised or shut in about two minutes; the cylinders are lined with copper and are double-acting. Wherever the height above the head of the sluice is limited by the ground level, the hydraulic cylinders are placed horizontally underground, as shown in Fig. 11, and the sluices are then weighted sufficiently to shut them against the pressure of the head of water. Where the pressure from the head of water in the culverts may be in either direction, two separate sluices are used in the same well, with their faces in opposite directions; excepting in the case of the sluice K, Fig. 6, between the two pump wells, and also the one situated at L in the branch suction culvert to the upper pump, where special and somewhat novel arrangements are adopted.

The sluice at L, Fig. 6, in the branch suction culvert to the upper pump, is made with two parallel faces, as shown in Fig. 14, Plate 47, with a small clearance between these and the iron frames fitted in the masonry, in order that the sluice may go down easily into its place; the pin-joint in the rod working the sluice is also made with a similar clearance, so that the sluice door is free to close tight upon the face against which the pressure forces it. By this arrangement considerable economy is effected, as an additional ram is saved and there is also somewhat less cost in the manufacture of the sluice thus made than in making two independent sluices.

The other double-faced sluice, situated at K between the pump wells, Figs. 5 and 6, is made of a wedge shape, as shown in

Figs. 12 and 13, Plate 47; it is fitted with hard wood on the bearing surfaces, resting on granite facings. The hydraulic cylinder for this sluice is horizontal and single-acting, the weight of the sluice being sufficient to close it.

For drainage purposes, a separate well is provided at M, Fig. 6, Plate 44, containing two bucket-lift pumps of 20 in. diameter and 33 in. stroke, worked by a small pair of engines with 14 by 18 in. cylinders. These are almost constantly at work for pumping out the water leaking into the emptied docks; a pair of sluices at N N, Fig. 6, worked by hand, admit the water from the branch suction culverts A A to the drainage well M. These pumps also give the means of emptying the two main pump wells, so that the main pumps can be left dry and accessible at all times when they are standing. Self-acting flap-valves opening outwards, made of wood and leather, are placed at P P in each of the main discharge culverts, for preventing the discharged water from returning into the pump wells.

The same system of pumping out the docks as that adopted at Chatham has also been applied by the writer's firm at the new dry docks in course of construction at Rio de Janeiro for the Brazilian Government, as shown in Fig. 16, Plate 48; the capacity of each dock is estimated at 21,600 tons with a depth of water of 29 ft., and the time required to empty the dock is 3 hours. The pumps and wells are shown in section and plan in Figs. 17 and 18, Plates 49 and 50. The pumps are $6\frac{1}{2}$ ft. diameter, and are driven by a pair of horizontal compound engines, of 300 Ind. H. P., with tubular boilers.

Mr. RENNIE mentioned that the hydraulic rams for the sluices described in the paper at the Chatham docks had been supplied by Sir Wm. Armstrong and Co., and fitted up in place by his own firm. As an example of the amount of friction of the water in passing through the culverts, it might be stated that in a recent trial, in pumping out Nos. 3 and 4 docks at the same time, it was observed that in about $\frac{1}{4}$ hour after the pumping had commenced there was a difference of 5 in. between the levels of the water in the two docks; this difference was maintained until the velocity of the water in the culverts was reduced, when the levels gradually became more nearly equal. This could only be accounted for by the friction of the water passing through the portion of culvert intervening between the two docks. With such a difference as was thus shown, due to so short a length of culvert, it was manifest that a considerable allowance in the results given in the paper must be made for the true duty of the pumps, on account of the power absorbed by the friction of the water in passing through the whole length of the culvert from the docks to the pumps, which was over 1000 ft.; besides the several sharp bends, which could not be obviated.

Mr. E. A. COWPER said that in reference to the proper curve for the arms of centrifugal pumps he had come to the same conclusion as had been stated in the paper. It was an involute curve, such as would be described by a point in a string unwinding from a cylinder; and although any two knots made in the string would remain the same distance apart, yet the curves described by them would not be exactly parallel or equidistant throughout, because the string was never at right angles to the curves it was describing at any moment. Consequently the distance between the arms in the pump was not the same from the centre to the circumferenee; and in order to preserve a uniform area of passage, the width of the arms themselves had therefore to be tapered gradually towards the circumference, according to the shape shown in the diagrams.

As it appeared the friction in the short length of culvert between two adjacent docks was sufficient to produce 5 in. difference of

level in $\frac{1}{4}$ hour, the increased friction due to the total length of the 7 ft. culvert, together with the high velocity of 468 ft. per min. which was stated to have been maintained through the culvert, seemed to him enough to account for a considerable reduction in the useful effect obtained, as measured by the actual quantity of water pumped. He enquired whether there was any special advantage in employing a number of collar bearings at the top of the pump shaft, as shown in the drawing, instead of placing a fixed cover-plate immediately above the pump to take off the pressure of the column of water on the top of the pump. He asked also why the wedge-shaped double-faced sluice, shown in Fig. 13, Plate 47, was faced with wood, while the other double-faced sluice, shown in Fig. 14, was fitted with metal faces.

Mr. Rennie replied that the object of placing the collar bearings at the top of the pump shaft was to provide the means of adjusting from the top of the well the clearance of the pump when working, so that its bottom face should be made to run always just clear of the top of the suction pipe underneath it; the weight of the column of water above the pump did not seem to be so excessive as to prevent its working most satisfactorily. The wedge-shaped sluice with wood faces was used only in the intermediate culvert between the two pump wells, where there was scarcely space enough for putting in an iron framing for the sluice; the wood faces bearing against the granite faces of the chamber had proved sufficiently tight with the wedge-shaped sluice.

Mr. Jeremiah Head enquired whether there was any liability of the bottom of the groove into which the sluice fell getting choked with sand or dirt. Being so small, it appeared to him that it might very easily get choked up, and so prevent the sluice from closing.

Mr. Rennie replied that no difficulty or inconvenience had been experienced from that cause at present. It was quite possible that any grit contained in the water might be washed into the groove; but if so, it would only be necessary to lift the sluice when there was no water in the pump wells, and the groove could then be easily cleaned out.

Mr. Benjamin Walker said he had had great pleasure in seeing the pumping engines at Chatham, described in the paper, and they were certainly fine specimens of mechanical skill and workmanship; they were very solid and substantial, and the various contrivances connected with them were well adapted to their purposes. He understood Mr. Rennie had made some careful experiments as to the amount of power developed in the engines, by measuring the quantity of water from the surface condenser, so as to ascertain exactly how much steam had been used in the engines; and it would be very interesting to have the particulars of the results obtained by this mode of ascertaining the power developed in the working of a steam engine.

Mr. G. D. Hughes enquired whether the consumption of fuel per thousand tons of water pumped out of the docks by these engines had been ascertained.

The President observed that this information was given in the paper in the form of the percentage of useful effect realised by the pumps; and as it was generally known what was a fair and proper consumption of coal for a well constructed steam engine, the actual consumption for the work done could be readily calculated from those data.

Mr. Rennie said that in a recent trial of a pair of very similar marine engines in a vessel of their own make, supplied with steam by tubular boilers instead of the Cornish boilers, the consumption had been 2·07 lbs. of coal per Ind. H. P. per hour, the speed of the engines being $87\frac{1}{2}$ rev. per min, instead of 86 to 88 as named in the paper, and the mean Ind. H. P. very nearly the same as in the pumping engines at that speed.

The measurement of the quantity of water from the surface condenser had been carried out in the trial recently made of the Chatham pumping engines, and he would supply the particulars.*

* Particulars of the trial made on 13th July to ascertain the amount of steam used in pumping out two docks, Nos. 3 and 4, containing together 67,660 tons of water, by measuring the total water condensed in the engines during the work. The feed pipe was disconnected from the hot-well, and all the water condensed in the surface condenser, in the steam jackets of the

Mr. W. H. Maw enquired whether any endeavour had been made to determine the friction of the water in the culvert by running the water back through the culvert into the dry dock, so as to refill the latter after it had been emptied. If this could be done, and the time required for so filling the dry dock to various depths were recorded, an exact measure would be obtained of the loss of power caused by the friction in the culvert and the contractions at the sluices.

Mr. Rennie replied that no experiment of that kind had been made, and it would not be easy to arrange such a trial, owing to the difficulty of letting the water run back through the pumps, on account of the self-acting flap-valves in the discharge culverts from the pumps, which prevented the return of the water. Each dock was filled by admitting the water direct from the basin through two separate short passages, each 3 ft. wide and 6 ft. high; and the time occupied in filling the docks in this way by gravity was

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cylinders, and in the steam pipes, was discharged into measuring tanks. The mean indicated horse power was ascertained by taking indicator diagrams every ten minutes.

3 hours 32½ min., time of working engines full speed.
3 hours 40 min., total time of working engines.
891·5 Ind. H. P., mean total power of engines.
87·6 rev. per min., mean speed of engines (taken by a counter).

60,228 lbs. water collected from hot-well.
1,312 lbs. „ „ „ steam jackets.
315 lbs. „ „ „ steam pipes.

61,855 lbs. total condensed water.

Consequently 61,855 lbs. of water was used by the engines in doing the work, equivalent to 18·92 lbs. per Ind. H. P. per hour. The coal used in the trial was Fothergill's Aberdare, and taking the evaporative duty according to the Admiralty returns at 9·73 lbs. of water per lb. of coal, the consumption of coal would be equal to 1·94 lbs. per Ind. H. P. per hour. The consumption of coal during the trial was approximately estimated at 5½ tons; but the time of the trial was too short to estimate the actual amount, and to get the fires in the same state on completing the trial as at the commencement.

The surface condenser contains 2407 vertical copper tubes of 5 ft. 3 in. length and ¾ in. diameter, with a total condensing surface of 2480 sq. ft., the steam being inside the tubes and the water outside; the temperature of the condensed water in the hot-well during the trial was 92° Fahr.

about the same as that occupied in emptying any one of them by the pumping engines.

The PRESIDENT remarked that the paper now read was interesting, as showing how a uniform power could be applied to work against a head that varied considerably. From the result it appeared that 47 per cent. of the indicated horse power of the engines had been utilised in the water delivered. From the indicated horse power however must first be deducted from 16 to 20 per cent. for the friction of the engines themselves; and after making that deduction the percentage of useful effect was a very considerable one. Moreover there still remained the loss from the friction in the passage of the water through the culvert and bends. The velocity in the culvert during the first half of the pumping was 468 ft. per min.; and the friction at that speed being about 3-7ths lb. per square foot of wetted surface would account for a great deal of the unutilised power. The remainder must be attributed to the defect in the centrifugal pump itself; but it must be borne in mind that in all pumps, whether reciprocating or chain pumps, there was loss; and thus it was only the excess of loss in the centrifugal as compared with other pumps that could properly be charged as a disadvantage attendant upon its use. Considering the loss incidental to the centrifugal pump, the result of 47 per cent. useful effect was not unsatisfactory; and although such a percentage did not appear very high, it must be borne in mind that in the present instance the pumps were applied to empty dry docks, and to do it rapidly and not often. They were seldom wanted, and it seemed one of those cases where it was better to do the work with a simple machine, although not a very economically working one, than with a complex and costly machine standing idle for most of its time, which might cost more, in the loss of interest upon the heavy outlay required by its complicated construction, than would be saved by its more economical performance during the short periods of working. In selecting a machine for any particular purpose it was necessary to consider what was most desirable under all the circumstances, and not merely what was the most perfect mechanically. Such

consideration appeared to have been given in this instance by Mr. Rennie, who had successfully grappled with the difficulty of the varying head of water.

The PRESIDENT then proposed a vote of thanks to Mr. Rennie for bringing the subject before the Institution; this vote was passed.

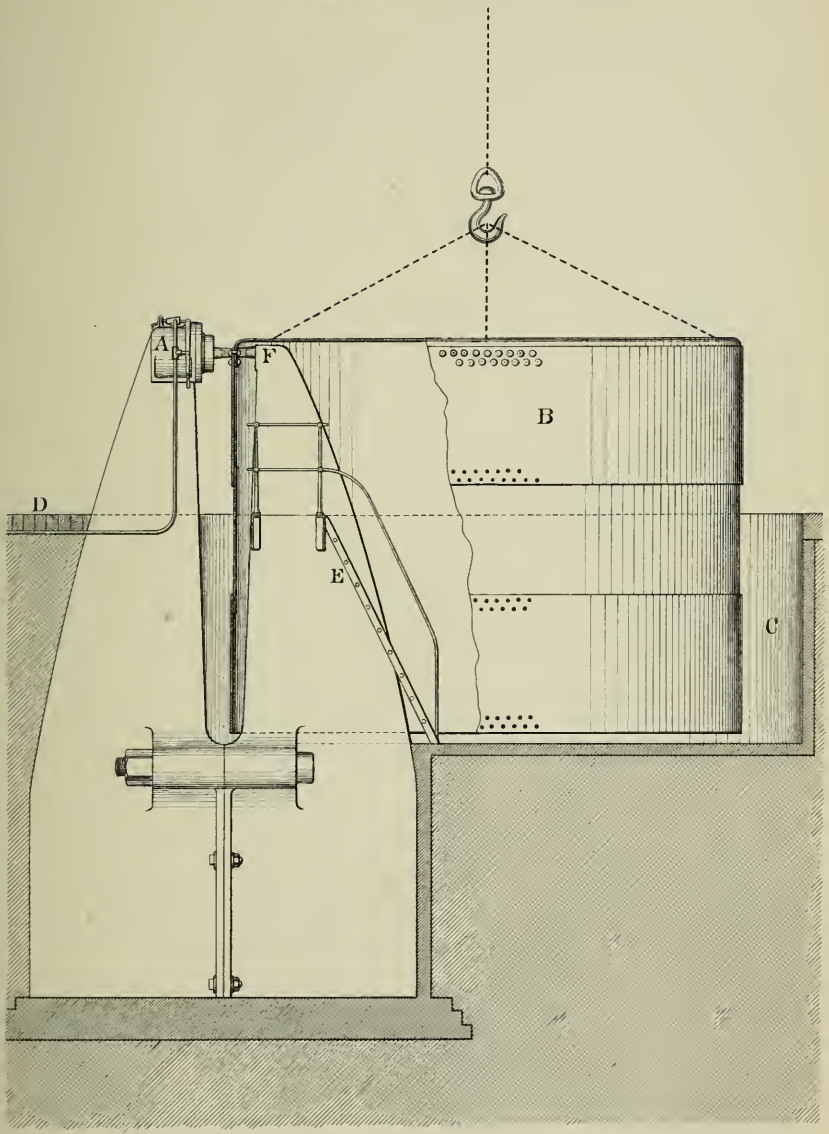
The Meeting was then adjourned to the following day.

In the afternoon an Excursion was made by the Members by special train to the Bute Docks, where the working of the hydraulic tips and balance tips for shipping coal, together with the portable hydraulic cranes, hydraulic hauling engines, and other machinery described in the paper read at the meeting, was shown by Mr. McConnochie; and the new basin and large entrance gates were seen.

The Penarth Docks were then visited, where there is a tidal dock 2100 ft. long and 370 ft. wide, having an area of about 18 acres, with an entrance basin of 3 acres area. The entrance gates are 60 ft. wide, and are opened only at high tide for the passage of vessels, the depth of water in the dock and basin being 25 ft. at neap tides and 35 ft. at spring tides. The coal shipping is on the high-level system by balance tips, of which there are ten at the dock and a double one at the basin, with hydraulic cranes for discharging ballast, and hydraulic power for working the dock gates. The mouth of the river Ely forms a tidal harbour, extending $1\frac{1}{2}$ mile with an average width for the first $\frac{3}{4}$ mile of 600 ft. at high water and 280 ft. at low water; the depth for this length is 5 ft. in the centre of the channel at low water. The tidal harbour has twelve balance tips for shipping coal; the depth of water in the berths at high water is 20 ft. at neap tides, and 30 ft. at spring tides. The dock and harbour are in communication with the different railways.

In the evening the Members were entertained at Dinner in the Drill Hall, Cardiff, by the President of the South Wales Institute of Engineers, Mr. T. Forster Brown.

Fig. 1. *Stationary Hydraulic Riveter for marine boilers &c.*

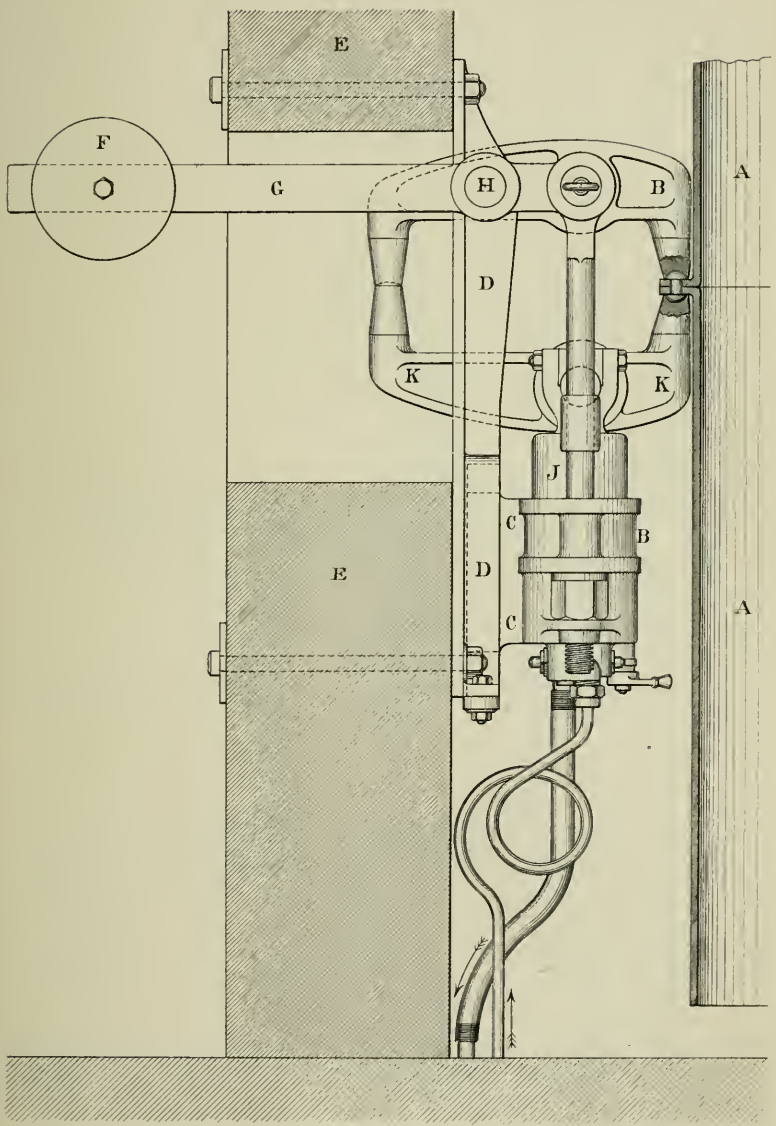


(Proceedings Inst. M. E. 1874)

Scale 1/60th.

0 5 10 15 Feet.

Fig. 2. *Portable Hydraulic Riveter carried upon bracket.*

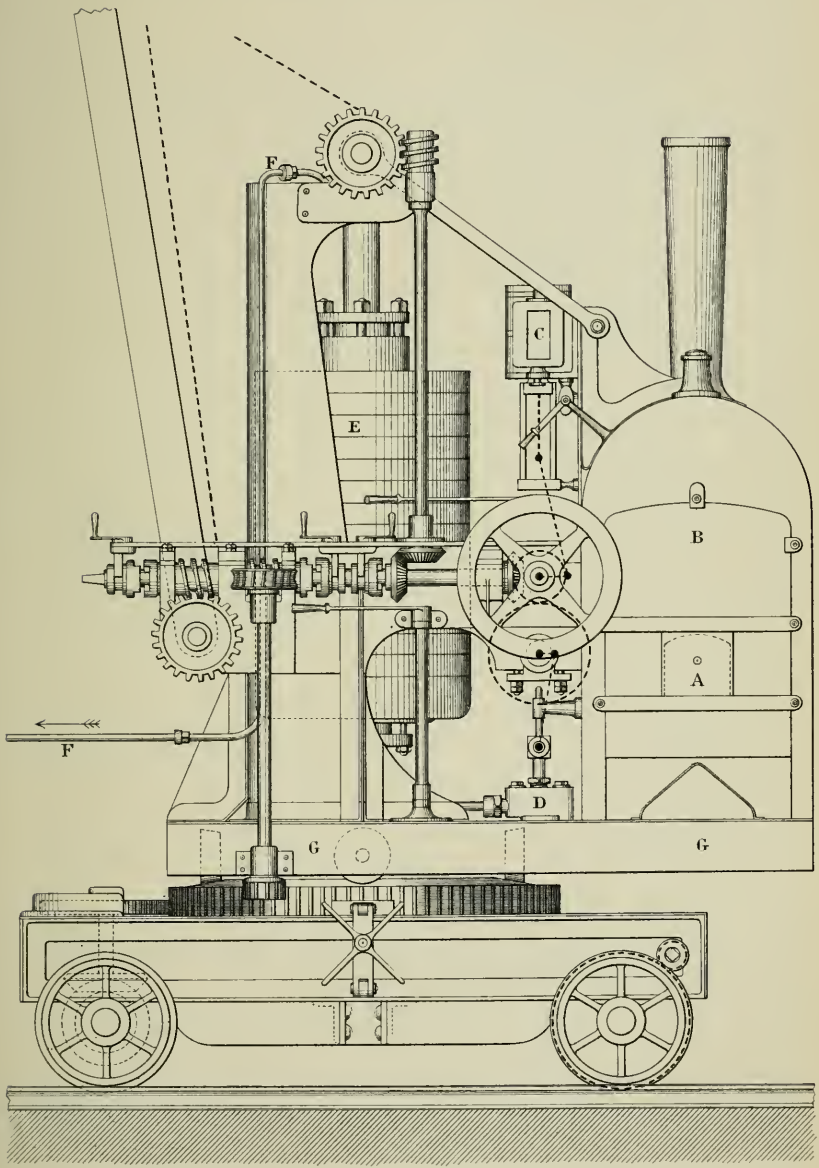


(Proceedings Inst. M.E. 1874)

Scale 1/12th.

Ins. 12 6 0 1 2 Fet. 3

Fig. 3. *Portable Hydraulic Riveting Plant.*



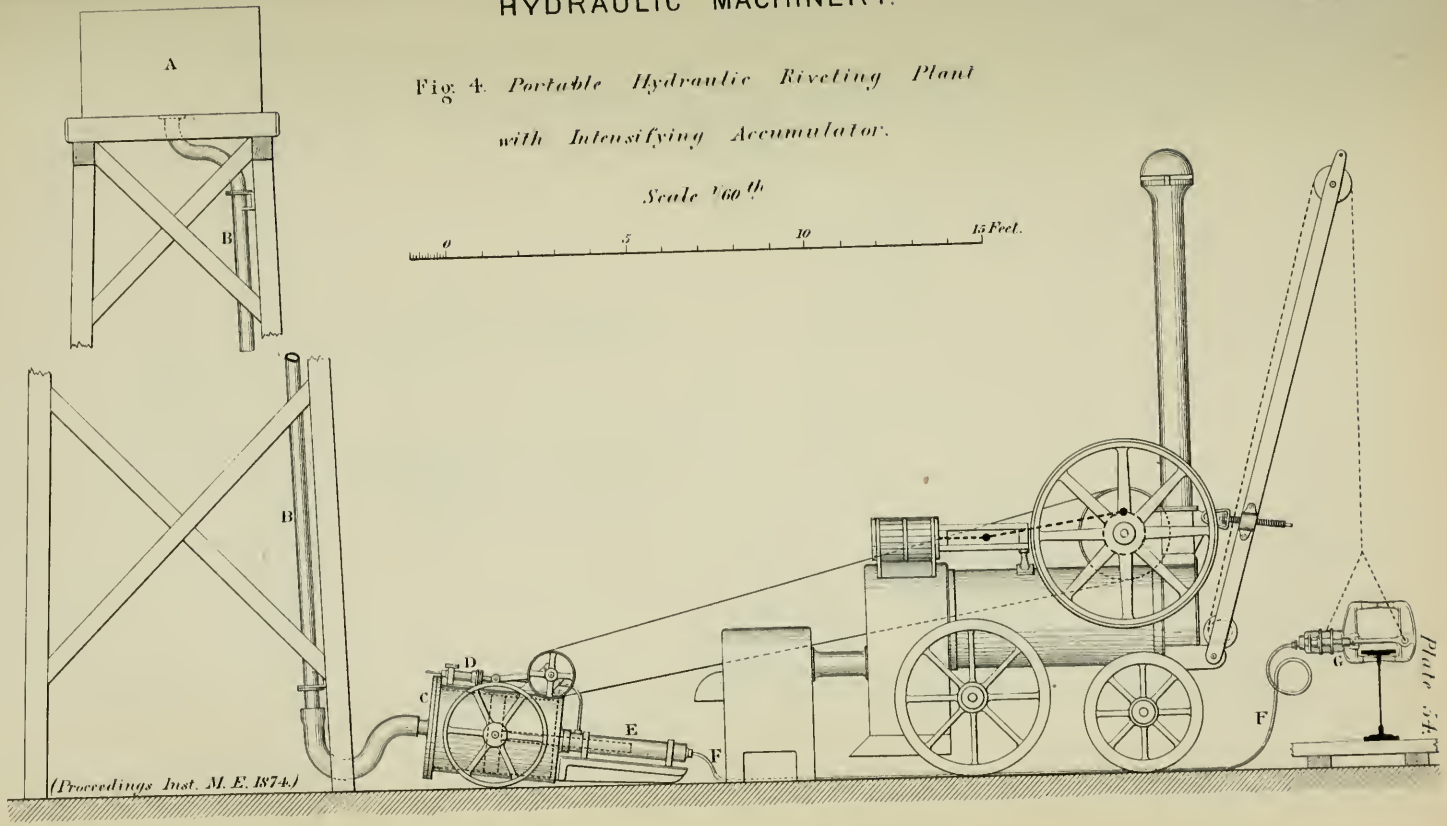
(Proceedings Inst. M. E. 1874.) *Scale 1/30 th.*

Ins. 12 6 0 1 2 3 4 5 6 7 8 Feet.

Fig. 4. *Portable Hydraulic Riveting Plant with Intensifying Accumulator.*

Scale 1/60th

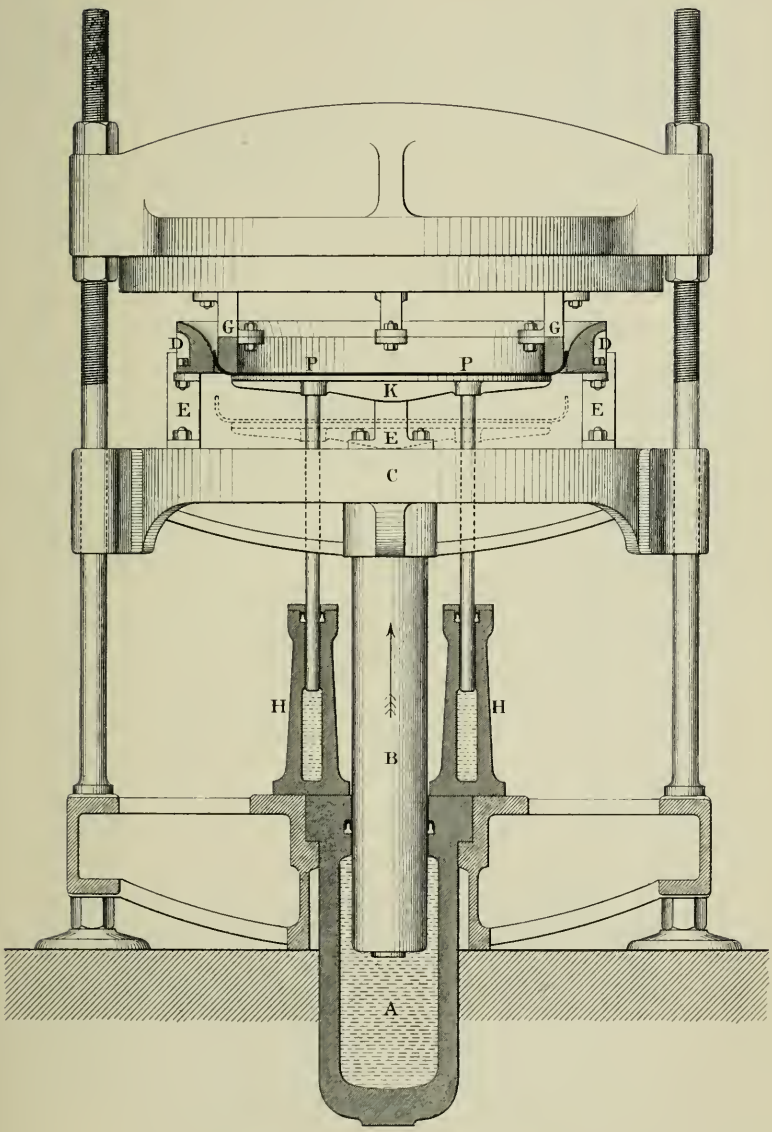
0 5 10 15 Feet.



(Proceedings Inst. M. E. 1874.)

Plate 54.

Fig. 5. *Hydraulic Flanging Machine.*



(Proceedings Inst. M. E. 1874.) *Scale 1/30 th*

Ins. 12 6 0 1 2 3 4 5 6 7 8 Feet.

Hydraulic Chain-Cable Shears.

Fig. 6. *Side Elevation.*

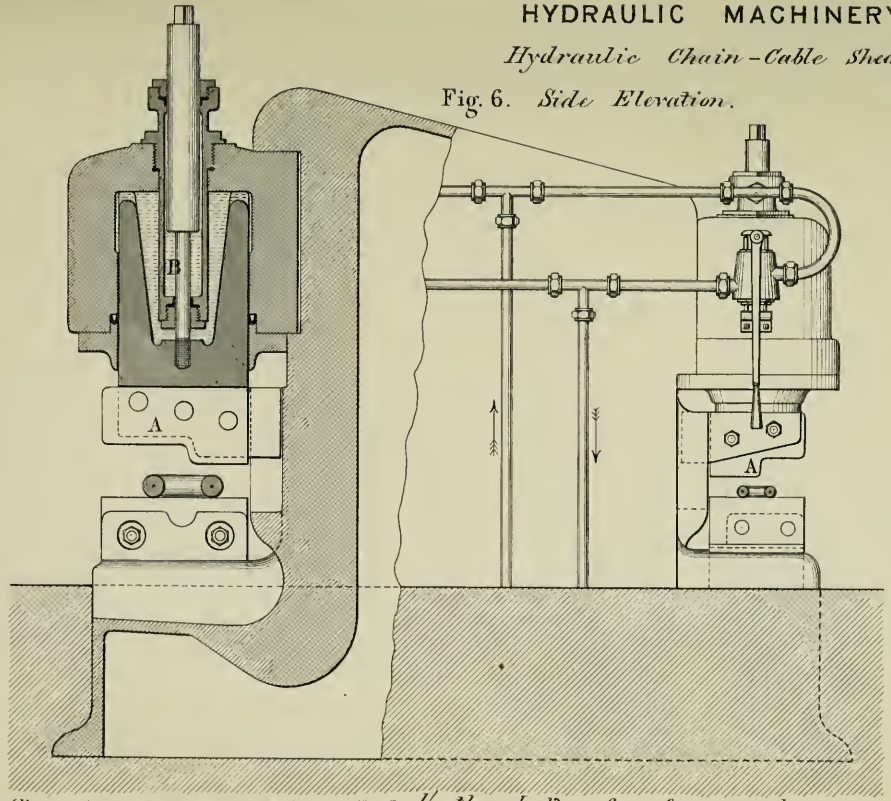


Fig. 7. *End Elevation.*

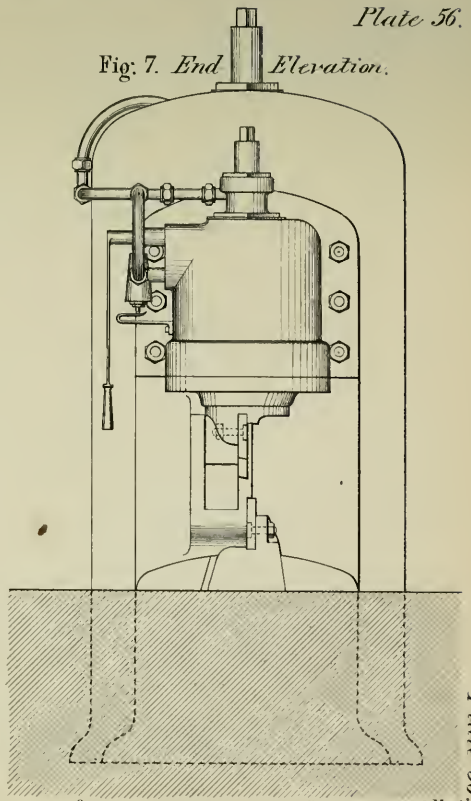
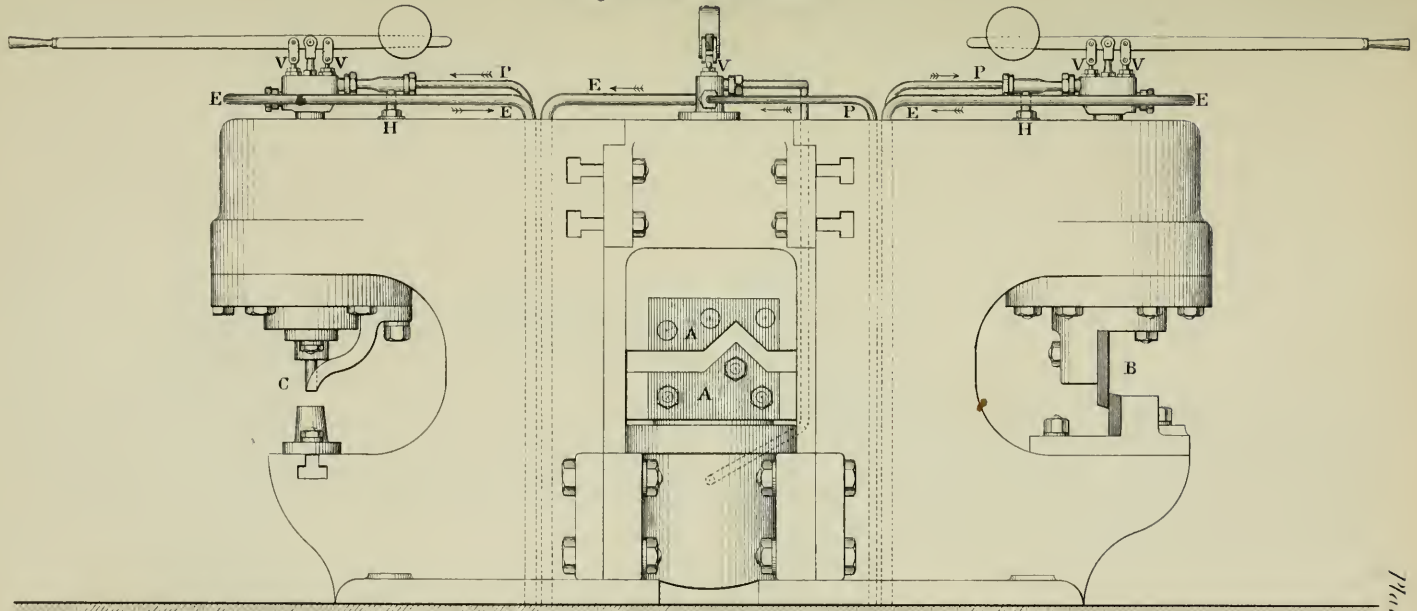


Plate 56.

(Proceedings Inst. M.E. 1874) Scale 1/20th Ins. 12 6 0 1 2 3 4 5 6 Feet

Hydraulic Punch and Shears.

Fig. 8. *Side Elevation.*

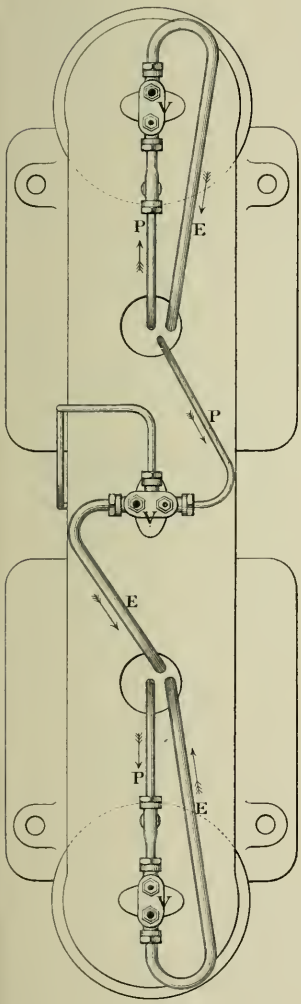


(Proceedings Inst. M.E. 1874.) Scale 1/20th Ins 12 6 0 1 2 3 4 5 Feet.

Plate 57.

Hydraulic Punch and Shears.

Fig. 9. *Plan.*

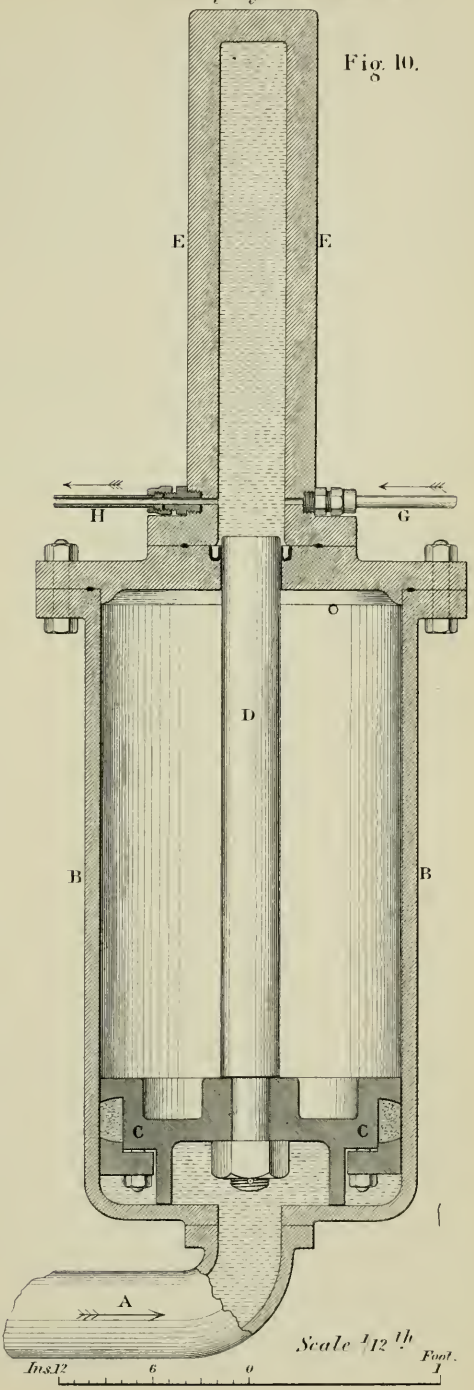


Scale 1/20 th

Ins. 12 6 0 1 Foot.

Intensifying Accumulator.

Fig. 10.



Scale 1/12 th

Ins. 12 6 0 1 Foot.

(*Proceedings Inst. M. E. 1874.*)

HYDRAULIC MACHINERY.

Hydraulic Corrugating Press.

Fig. 11. *Side Elevation.*

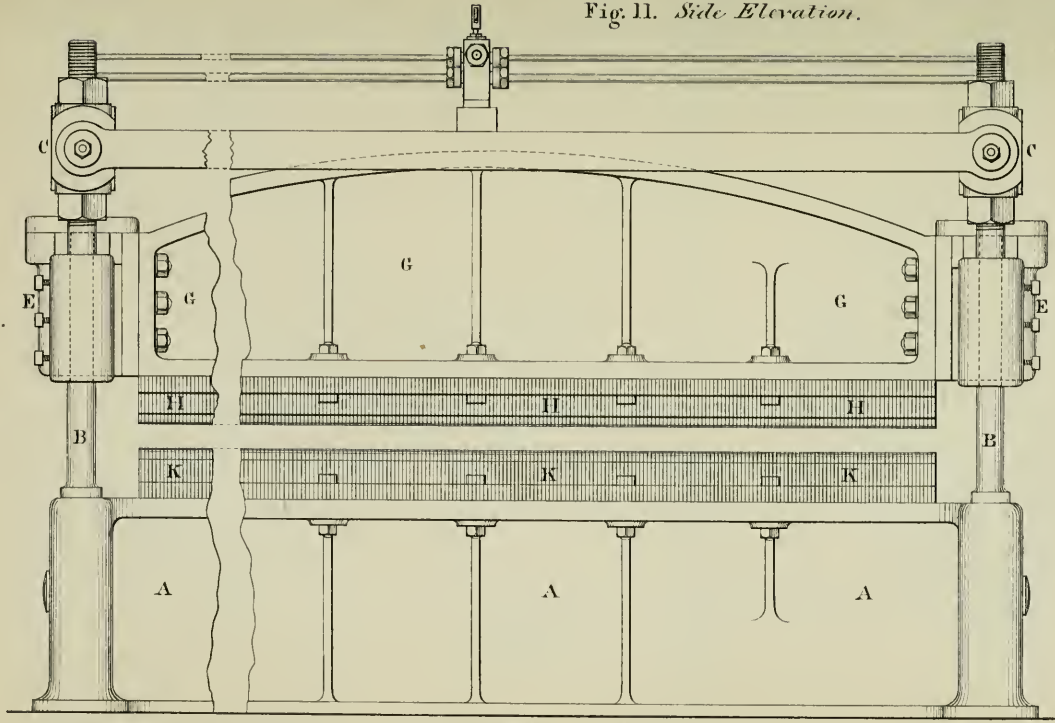


Fig. 12. *End Elevation.*

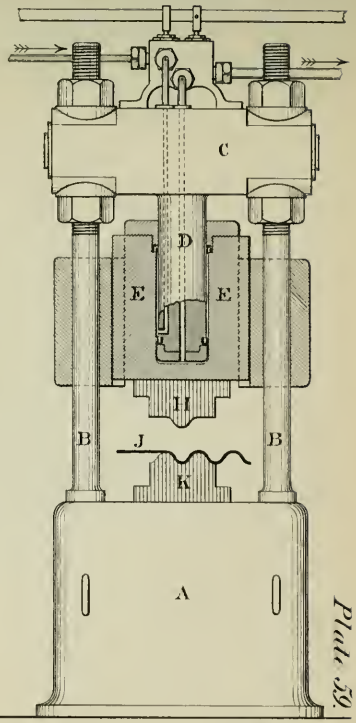


Plate 59.

(Proceedings Inst. M.E. 1874.)

Scale 1/24th.

Ins. 12 6 0 1 2 3 4 5 6 Feet.

Brotherhood's Three-Cylinder Hydraulic Engine.

Fig. 13. *Longitudinal Section.*

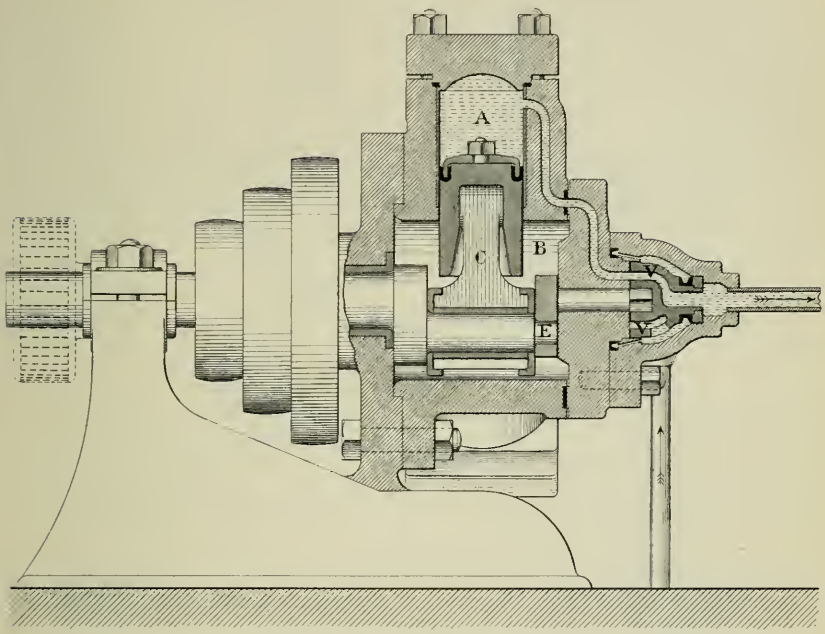


Fig. 14. *Transverse Section.*

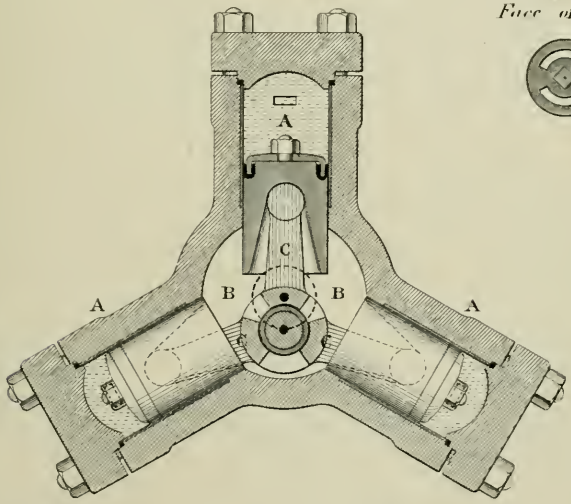
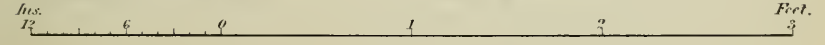


Fig. 15. *Face of Valve.*

(*Proceedings Inst. M.E. 1874.*)

Scale $1/12^{th}$



Leather Packings for Hydraulic Cylinders.

Fig. 16.

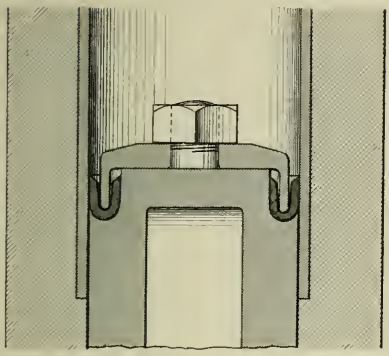


Fig. 17.

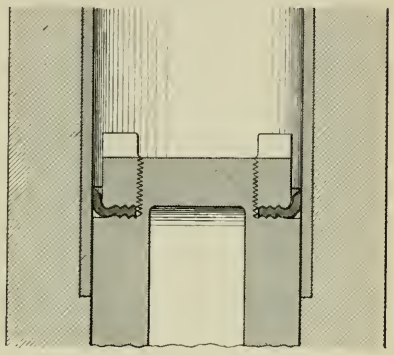


Fig. 18. *Metallic Packing for Hydraulic Plungers.*

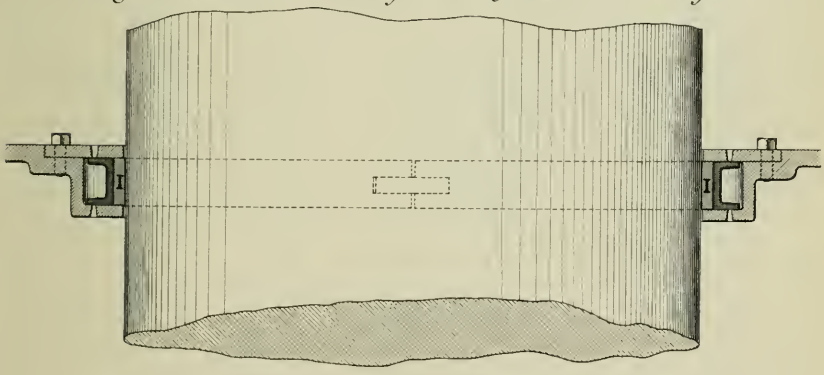
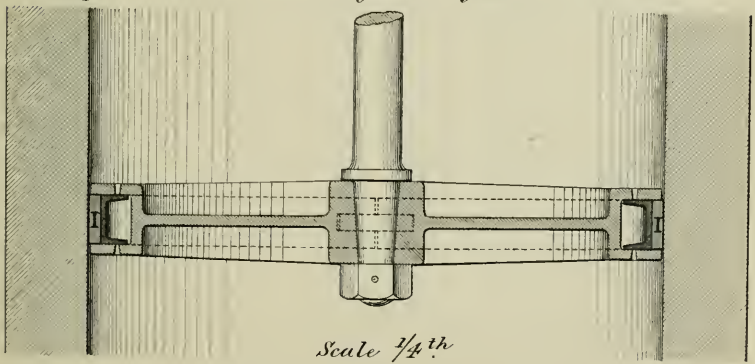


Fig. 19. *Metallic Packing for Hydraulic Pistons.*



Scale 1/4th

(Proceedings Inst. M.E. 1874)

0 1 2 3 4 5 6 Inches.

COMPRESSED-AIR MACHINERY.

Air-Compressing Engine.

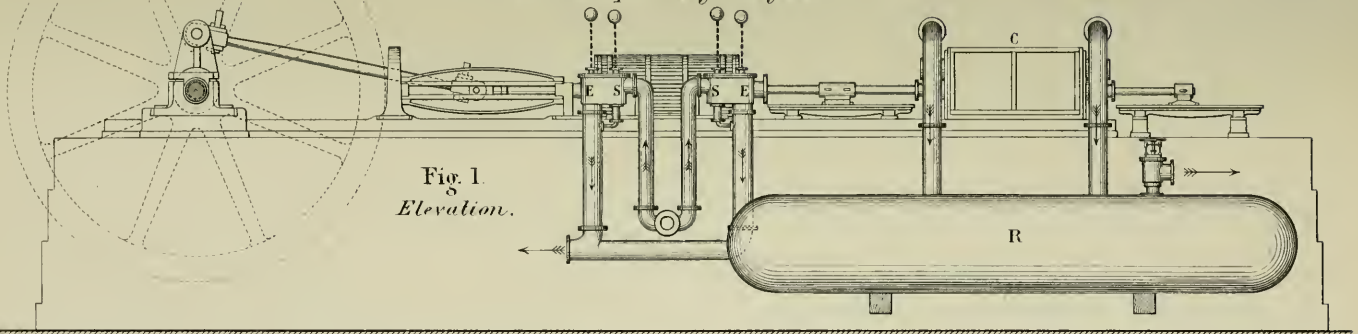


Fig. 1. *Elevation.*

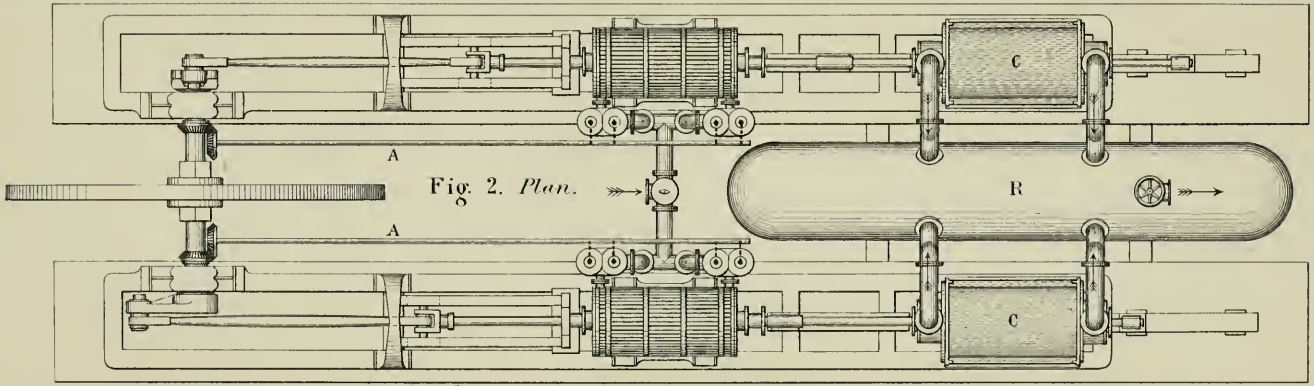


Fig. 2. *Plan.*

(Proceedings Inst. M.E. 1874.) *Scale* 1/120th.

10 5 0 10 20 30 Feet.

Plate 62.

Air-Compressing Engine.

Fig. 3.

Transverse Section of Steam Cylinder showing Steam Valve.

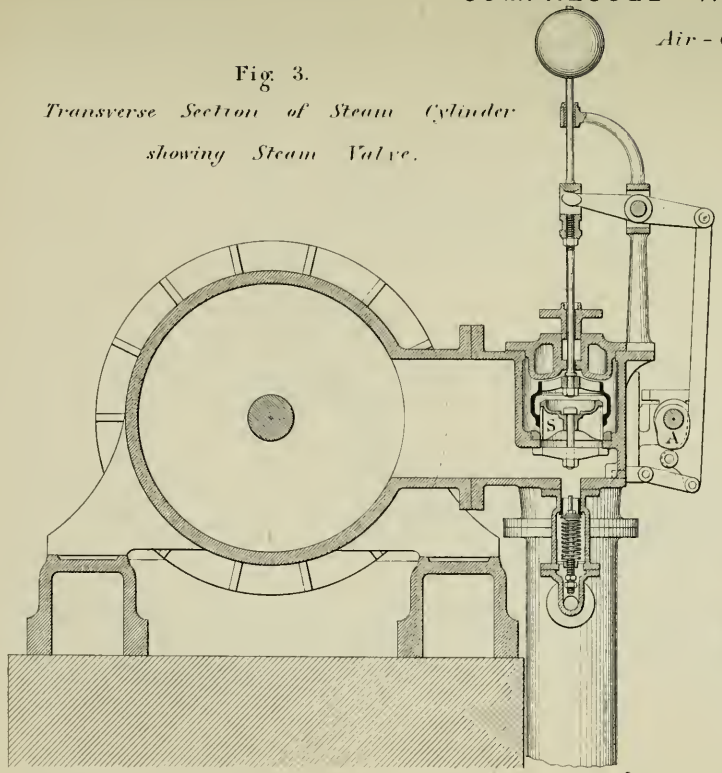
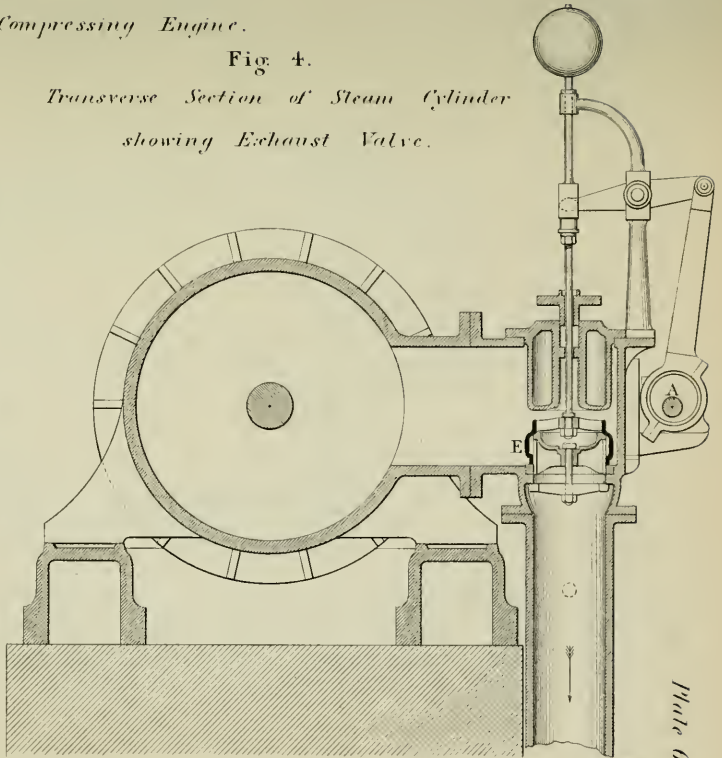


Fig. 4.

Transverse Section of Steam Cylinder showing Exhaust Valve.



(Proceedings Inst. M. E. 1874.)

Scale $\frac{1}{24}$th

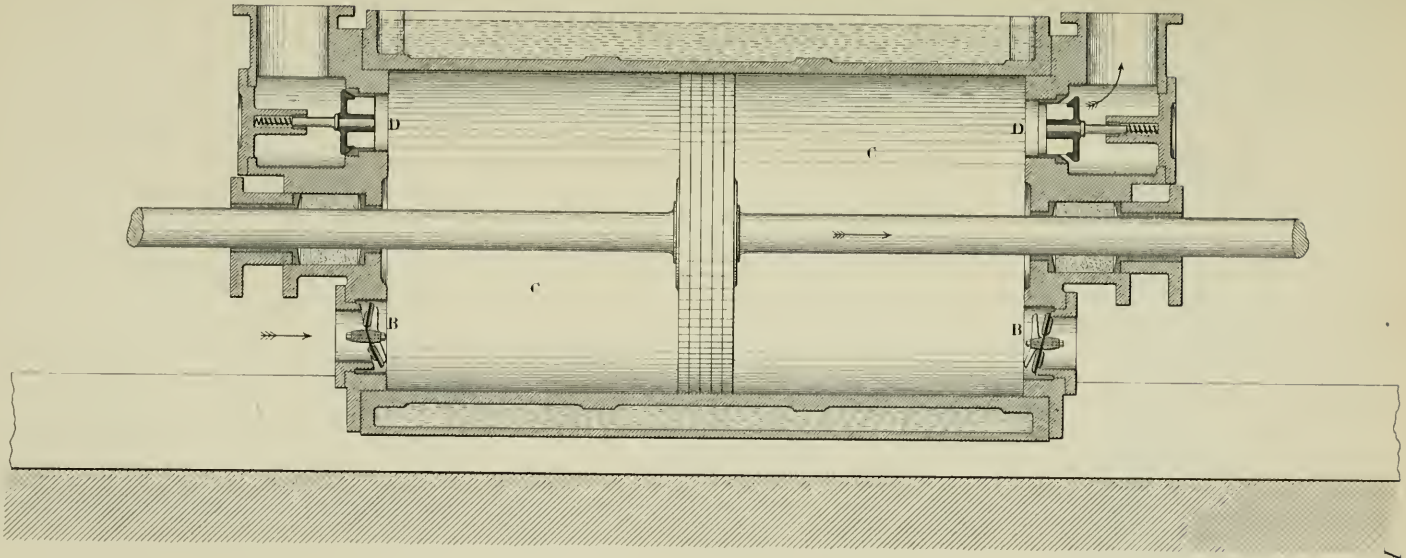
Ins. 12 6 0 1 2 3 4 5 6 Feet.

Plate 63.

COMPRESSED-AIR MACHINERY.

Air-Compressing Engine.

Fig. 5. *Longitudinal Section of Air Cylinder.*



(*Proceedings Inst. M. E. 1874.*)

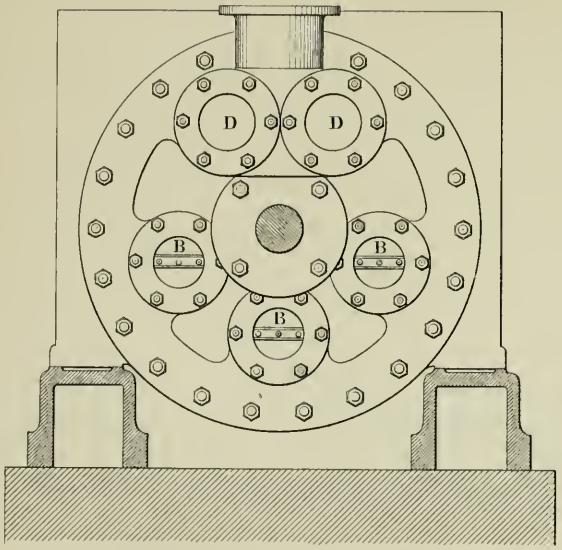
Scale 1/24 *th*

Ins. 12 6 0 1 2 3 4 5 6 Feet.

Plate 64.

Air-Compressing Engine.

Fig. 6. *End Elevation of Air Cylinder.*



(Proceedings Inst. M.E. 1874.)

Scale 1/24th

Ins. 12 6 0 1 2 3 4 Feet.

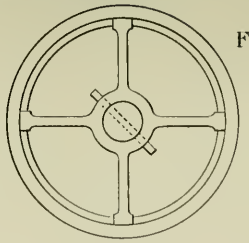


Fig. 7.

Outlet Valve.

Inside Elevations of Inlet and Outlet Valves. Scale 1/6th

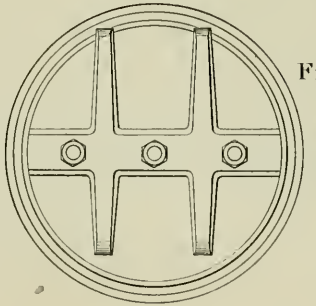


Fig. 9.

Inlet Valve.

Scale 1/6th

0 5 10 Inches.

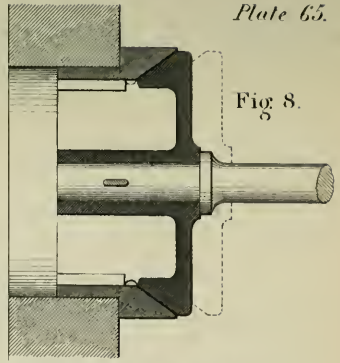


Fig. 8.

Longitudinal Sections.

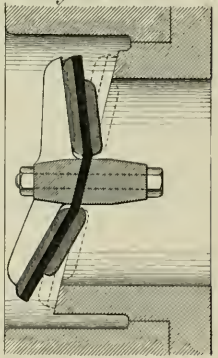


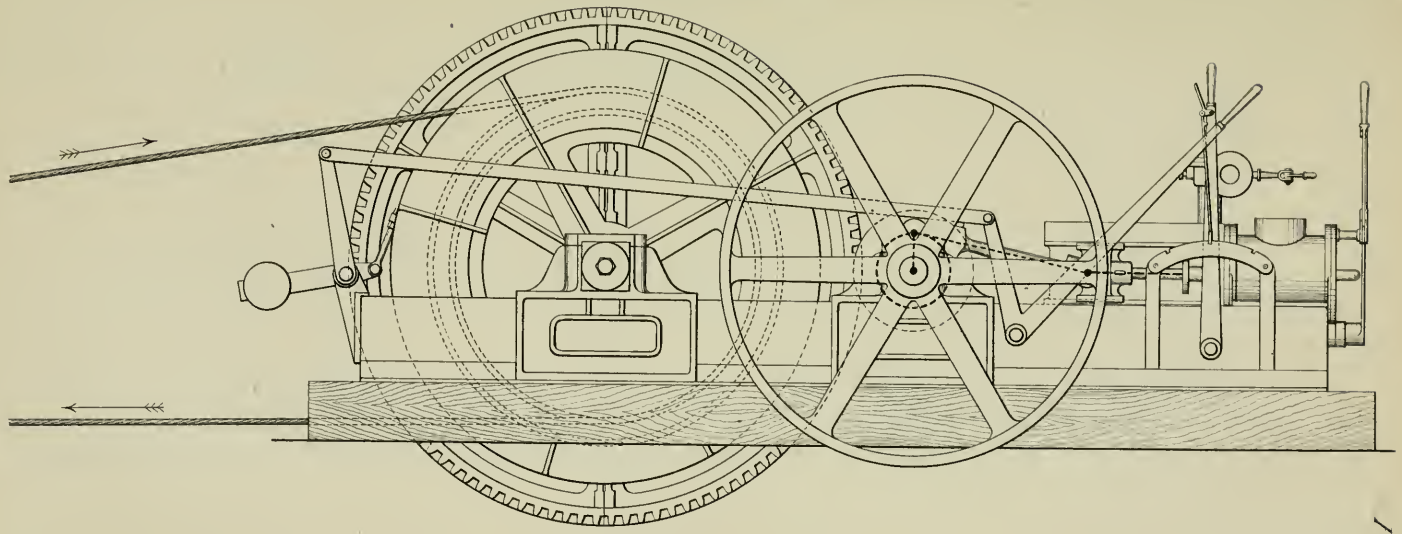
Fig. 10.

Plate 65.

COMPRESSED-AIR MACHINERY.

Fixed Hauling Engine.

Fig. 11. *Side Elevation.*

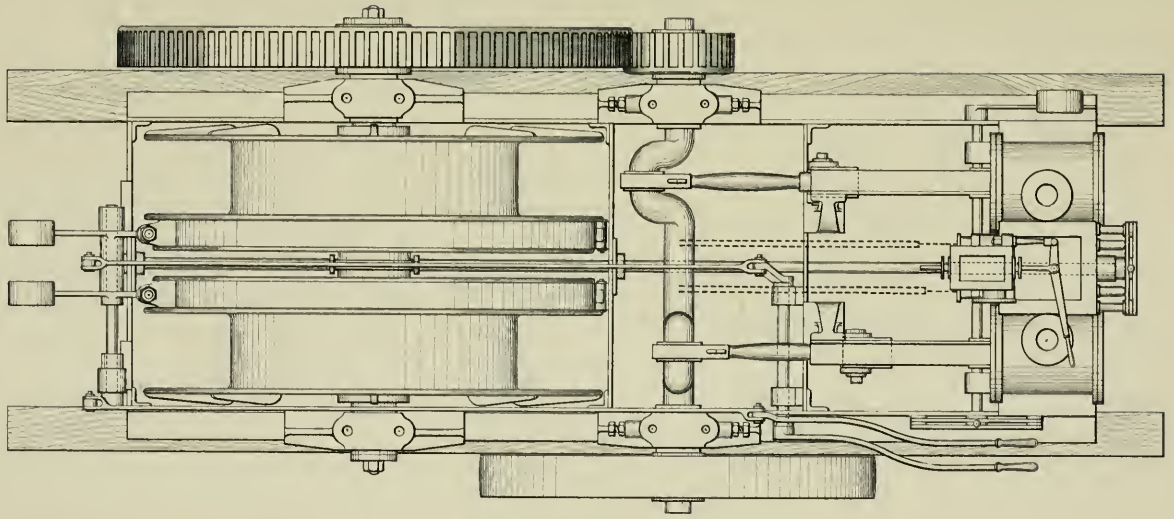


(Proceedings Inst. M.E. 1874) *Scale 1/32nd* 0 1 2 3 4 5 6 7 8 9 10 Feet.

Plate 66.

Fixed Hauling Engine.

Fig. 12. *Plan.*



(Proceedings Inst. M.E. 1874) *Scale 1/32nd* 0 1 2 3 4 5 6 7 8 9 10 Feet.

Plate 67.

Single-Cylinder Hauling Engine.

Fig. 13.
Transverse Section through Drums.

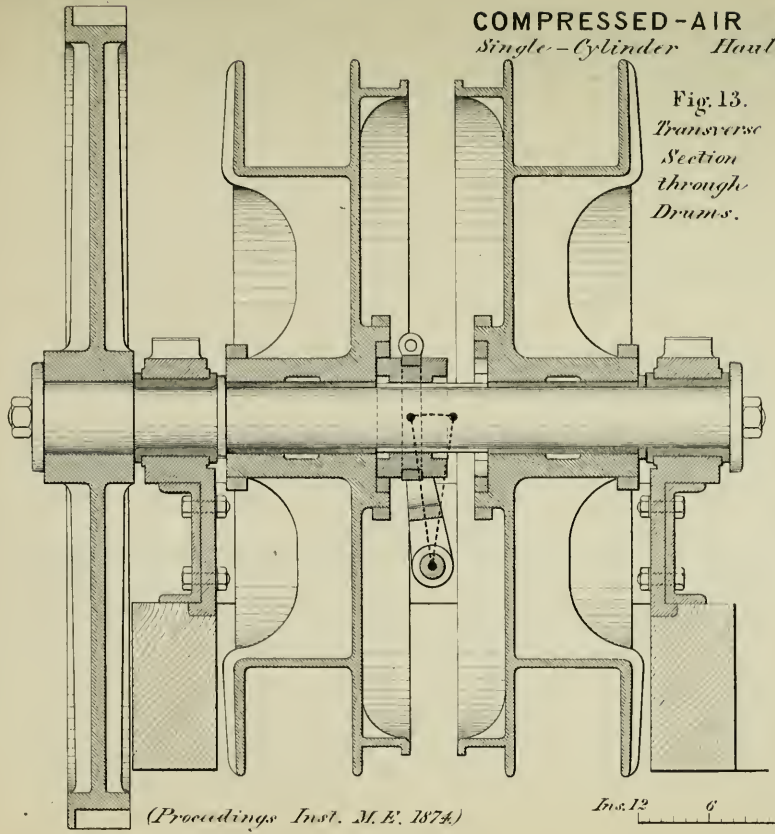
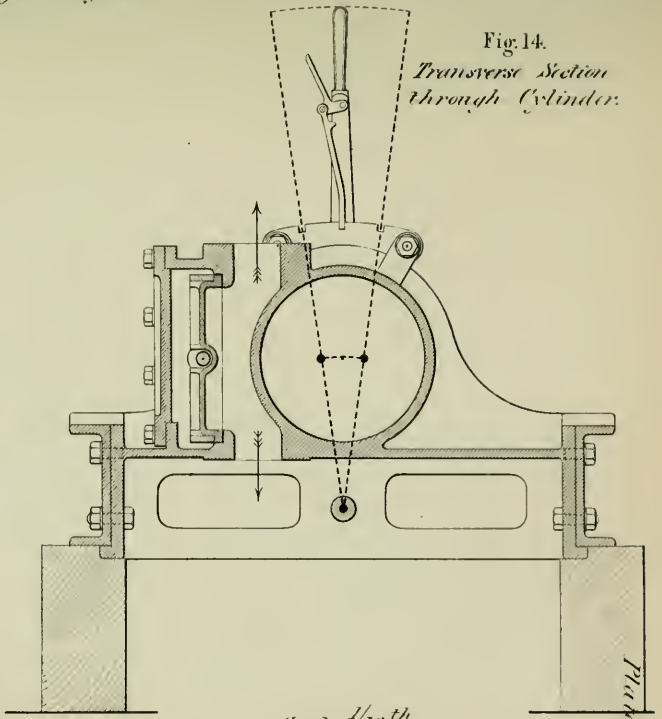


Fig. 14.
Transverse Section through Cylinder.



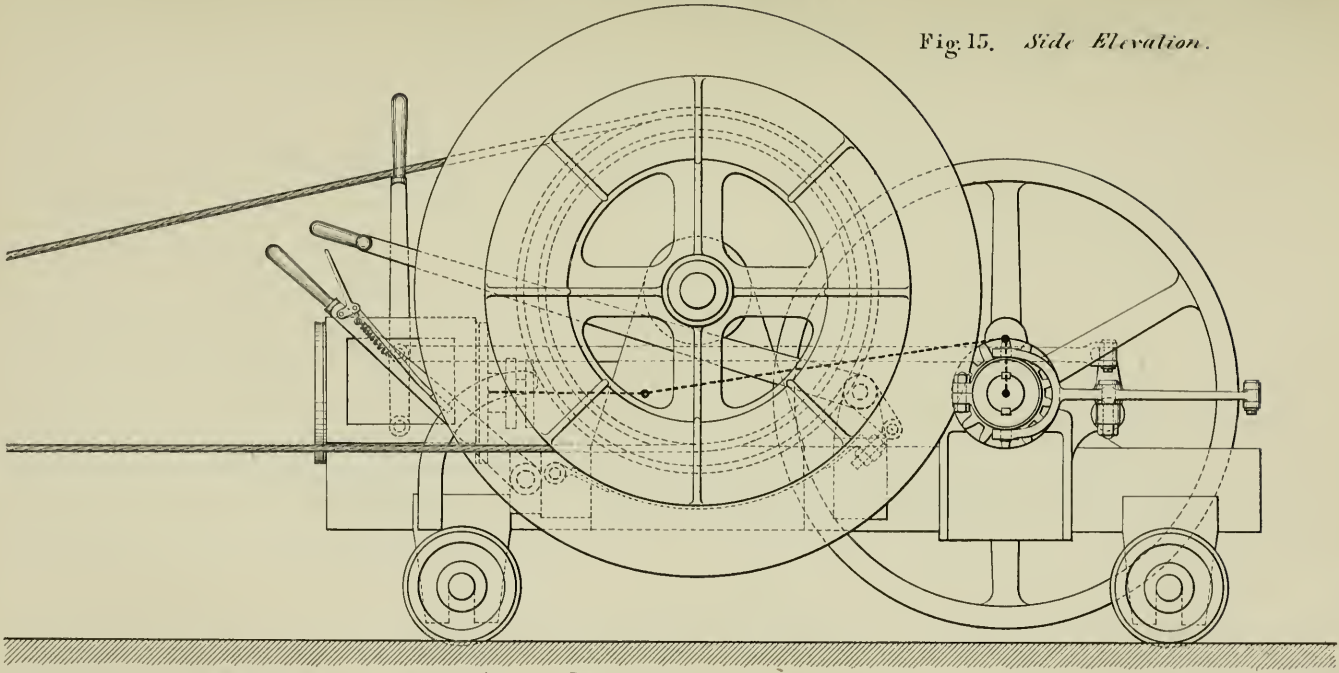
Scale 1/16th.

Ins. 12 6 0 1 2 3 Feet.

(Proceedings Inst. M. E. 1874)

Portable Hauling Engine.

Fig. 15. *Side Elevation.*

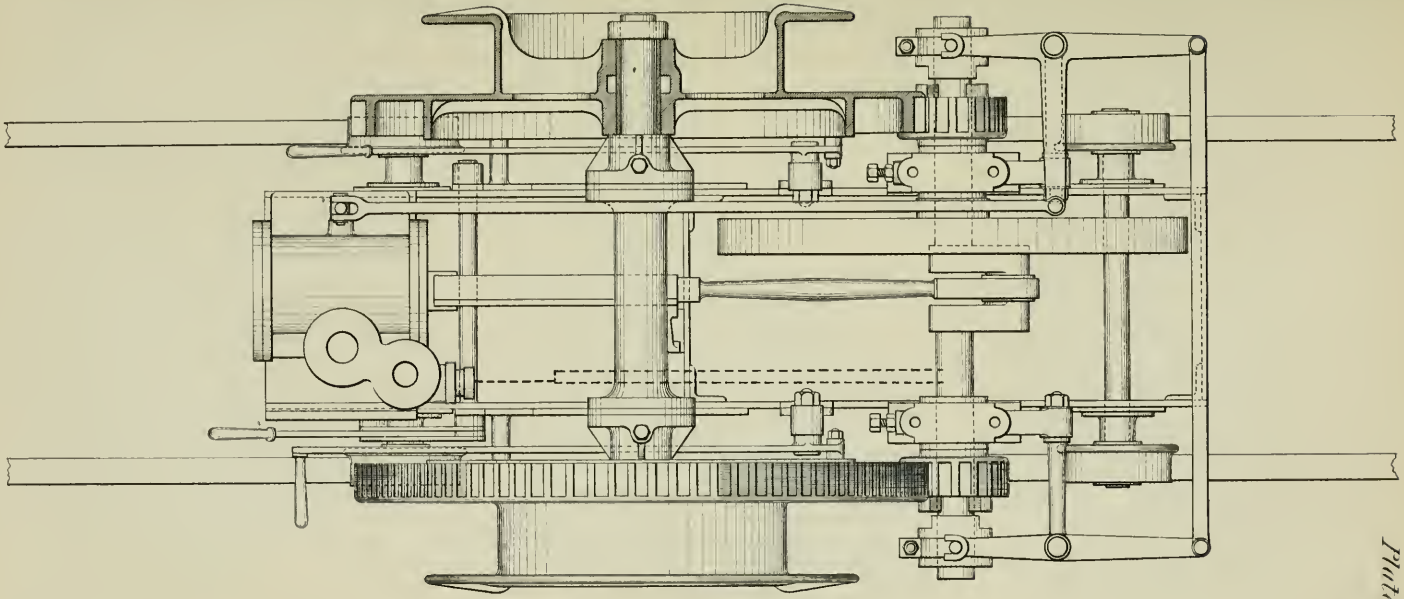


(Proceedings Inst. M. E. 1874.) *Scale 1/16th.* Ins. 12 6 0 1 2 3 Feet.

Plate 69.

Portable Hauling Engine.

Fig. 16. *Plan.*



(*Proceedings Inst. M.E. 1874.*) *Scale* 1/16th.

Plate 70.

Fig. 17. *Indicator Diagram from Steam Cylinder of Air Compressor.*
2 *cylinders* 16 *in. diameter* 2½ *ft. stroke.*
Lb. 38 *rev. per min.* 27·1 *lb. mean pressure* 61·2 *Ind. H.P.* *Lb.*

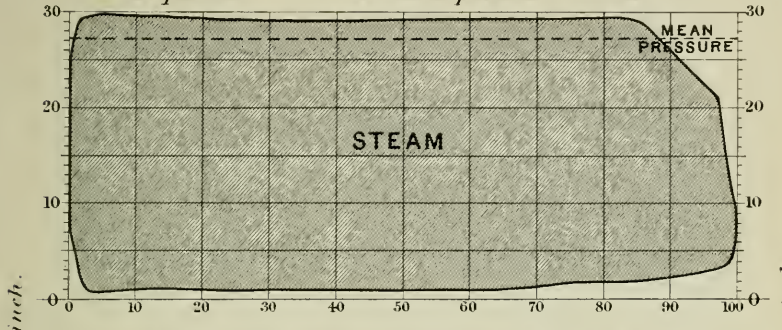


Fig. 18. *Indicator Diagram from Air Compressing Cylinder.*
2 *cylinders* 16 *in. diameter* 2½ *ft. stroke.*

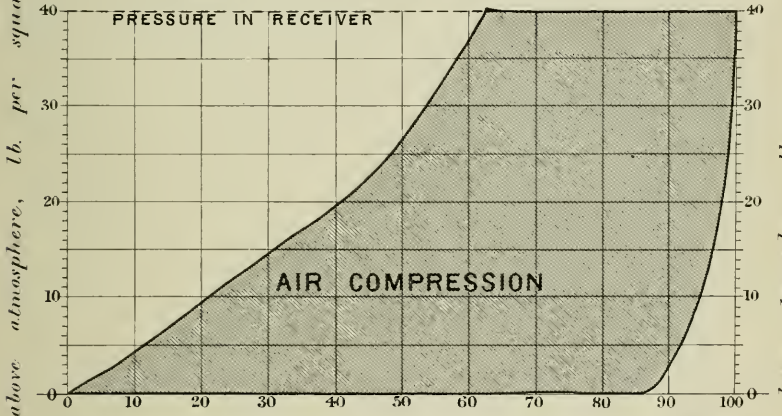
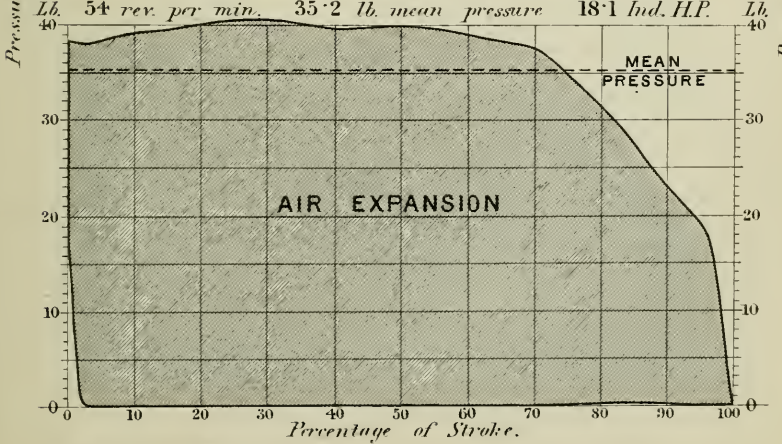


Fig. 19. *Indicator Diagram from Cylinder of Air Engine.*
2 *cylinders* 10 *in. diameter* 1 *ft. stroke.*
Lb. 54 *rev. per min.* 35·2 *lb. mean pressure* 18·1 *Ind. H.P.* *Lb.*



(*Proceedings Inst. M.E. 1874.*)

Fig. 20. *Indicator Diagram from Steam Cylinder of Air Compressor.*

2 cylinders 16 in. diameter 2½ ft. stroke

Lb. 31 *rev. per. min.* 25·0 *lb. mean pressure* 46·1 *Ind. H.P.* *Lb.*

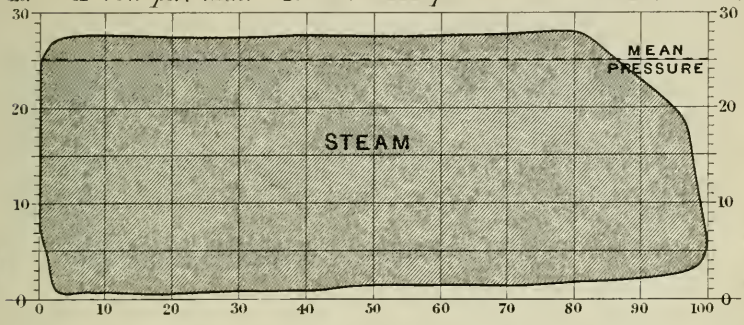


Fig. 21. *Indicator Diagram from Air Compressing Cylinder.*

Lb. *2 cylinders* *16 in. diameter* *2½ ft. stroke* *Lb.*

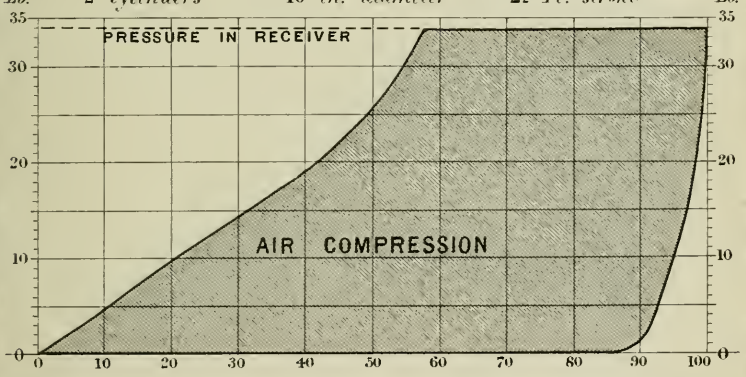
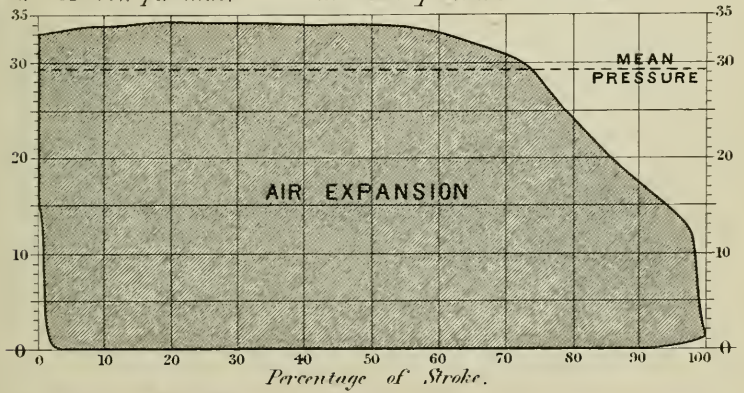


Fig. 22. *Indicator Diagram from Cylinder of Air Engine.*

2 cylinders *10 in. diameter* *1 ft. stroke*

Lb. 52 *rev. per min.* 29·3 *lb. mean pressure* 14·5 *Ind. H.P.* *Lb.*



(Proceedings Inst. M.E. 1874)

Fig. 23. *Indicator Diagram from Steam Cylinder of Air Compressor.*

2 *cylinders* 16 *in. diameter* 2½ *ft. stroke*

28 *rev. per min.* 21·6 *lb. mean pressure* 35·9 *Ind. H.P.*

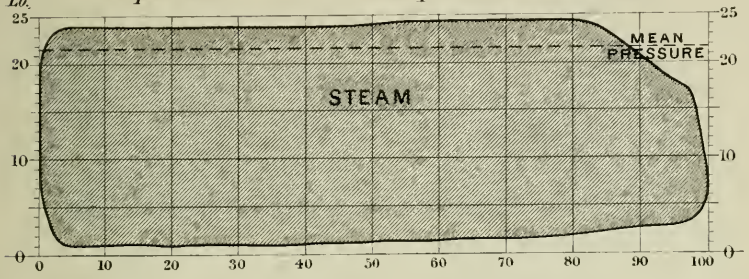


Fig. 24. *Indicator Diagram from Air Compressing Cylinder.*

2 *cylinders* 16 *in. diameter* 2½ *ft. stroke*

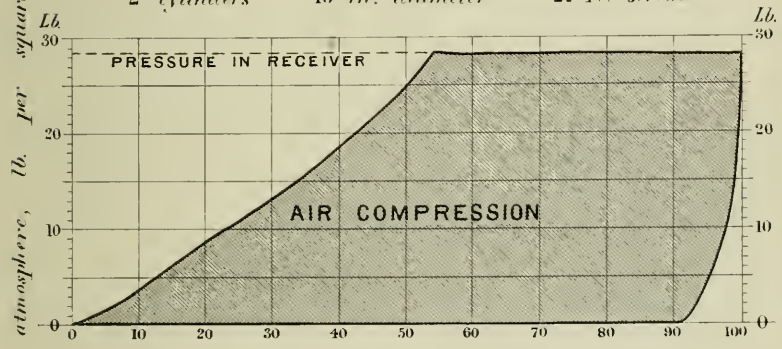
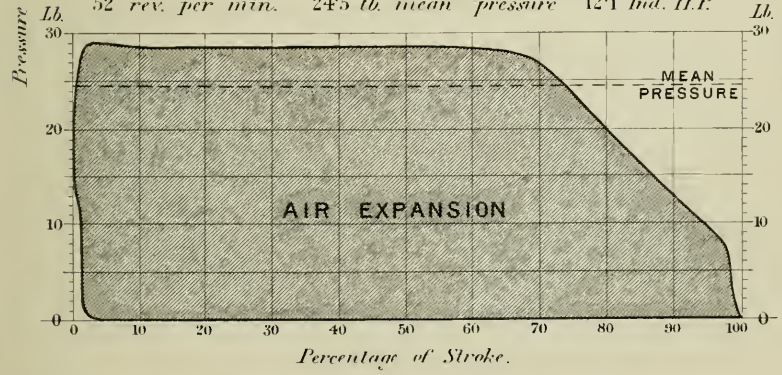


Fig. 25. *Indicator Diagram from Cylinder of Air Engine.*

2 *cylinders* 10 *in. diameter* 1 *ft. stroke*

52 *rev. per min.* 24·5 *lb. mean pressure* 12·1 *Ind. H.P.*



(*Proceedings Inst. M. E. 1874.*)

Fig. 26. *Indicator Diagram from Steam Cylinder of Air Compressor.*

2 *cylinders* 16 *in. diameter* 2½ *ft. stroke*

22 *rev. per min.* 19·7 *lb. mean pressure* 25·8 *Ind. H.P.*

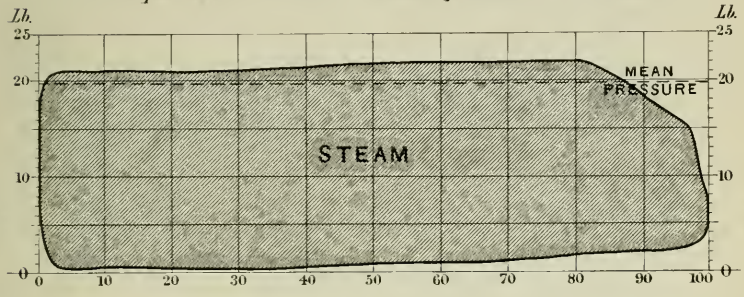


Fig. 27. *Indicator Diagram from Air Compressing Cylinder.*

2 *cylinders* 16 *in. diameter* 2½ *ft. stroke*

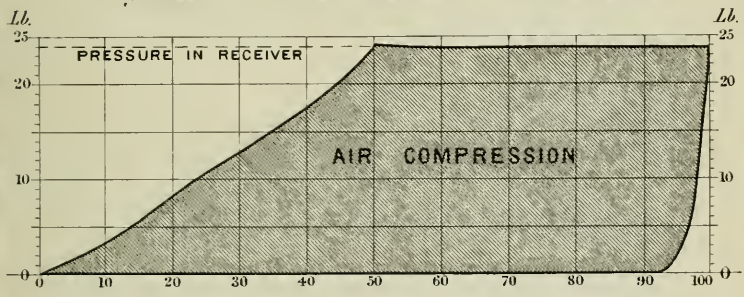
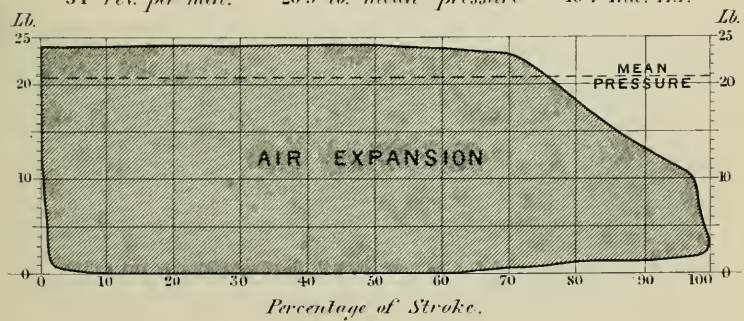


Fig. 28. *Indicator Diagram from Cylinder of Air Engine.*

2 *cylinders* 10 *in. diameter* 1 *ft. stroke.*

54 *rev. per min.* 20·9 *lb. mean pressure* 10·7 *Ind. H.P.*



(Proceedings Inst. M.E. 1874.)

Fig. 29. *Indicator Diagram from Steam Cylinder of Air Compressor.*
2 *cylinders* 16 *in. diameter* 2½ *ft. stroke*
12 *rev. per min.* 17·1 *lb. mean pressure* 12·2 *Ind. H.P.*

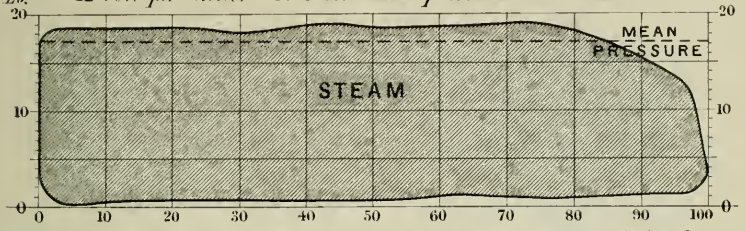
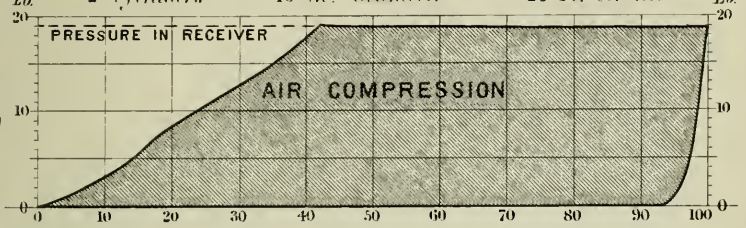
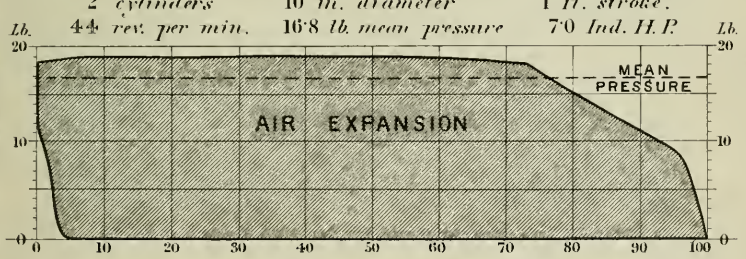


Fig. 30. *Indicator Diagram from Air Compressing Cylinder.*
2 *cylinders* 16 *in. diameter* 2½ *ft. stroke.*



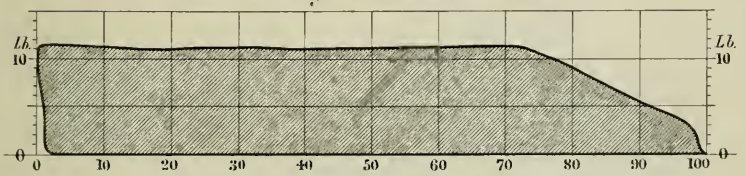
Lb. per square inch.

Fig. 31. *Indicator Diagram from Cylinder of Air Engine.*
2 *cylinders* 10 *in. diameter* 1 *ft. stroke.*
44 *rev. per min.* 16·8 *lb. mean pressure* 7·0 *Ind. H.P.*



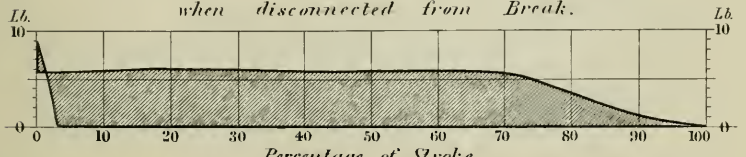
Lb. above atmosphere, Lb. per square inch.

Fig. 32. *Indicator Diagram from Air Engine when driving Unloaded Break.*



Pressure

Fig. 33. *Indicator Diagram from Air Engine when disconnected from Break.*



Percentage of Stroke.

(Proceedings Inst. M. E. 1874.)

Fig. 34. *Comparison of Theoretical Curves of Air Compression.*

ADIABATIC CURVE, *when no heat is abstracted during compression.*

HYPERBOLIC CURVE, *when the temperature is kept constant.*

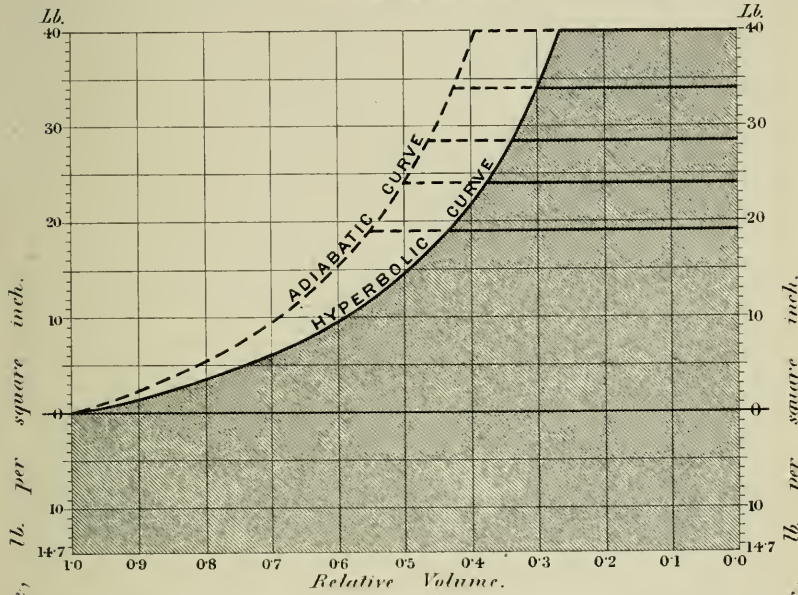
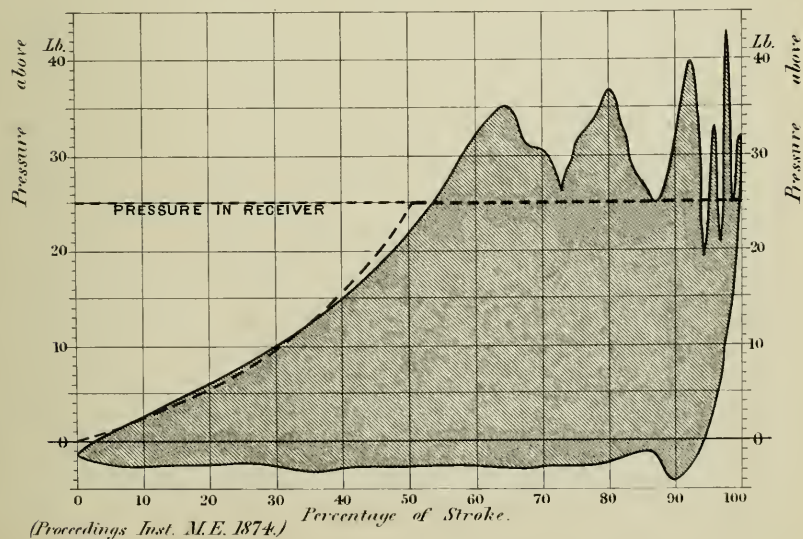


Fig. 35. *Indicator Diagram from Air Compressing Cylinder.*

16½ *in. diameter* 3 *ft. stroke* 34 *rev. per min.*



(Proceedings Inst. M.E. 1874.)

The Adjourned Meeting of the Members was held in the Assembly Room, Town Hall, Cardiff, on Wednesday, 5th August, 1874; Frederick J. Bramwell, Esq., F.R.S., President, in the Chair.

The following paper was read :—

ON THE APPLICATION OF WATER PRESSURE TO DRIVING MACHINERY AND WORKING SHOP TOOLS.

By Mr. RALPH H. TWEDDELL, of London.

The extension which has taken place in the application of Hydraulic Power to riveting is now considerable, and is a confirmation of the views expressed by the writer in a former paper as to the practicability of this principle; there are at the present time more than a hundred hydraulic riveting machines in regular work in this country, each exerting a closing pressure of from 25 to 40 tons, and putting in daily from 1500 to 2000 rivets each.

An objection has previously been raised that these machines involve a certain loss of power by the use of water at a high pressure through the first portion of the stroke in riveting, through which a lower pressure would be sufficient; but in reference to this objection it has to be observed that, when the accumulator capacity bears a sufficiently small proportion to that of the riveter cylinder, the advantage gained by utilising the momentum of the falling accumulator at the end of the stroke of the ram more than counterbalances the above loss. The closing pressure on the rivet head in the machines on the writer's plan is consequently considerably greater than that due to the pressure per square inch in the accumulator, and such a machine, while exerting nominally a pressure of 40 tons on the rivet, gives in many cases nearly 60 tons closing pressure. But this compensating advantage does not occur with a hydraulic riveter worked at a low initial pressure, or even with a high pressure when the quantity of water drawn from the accumulator at each stroke of the ram bears no considerable proportion to its total contents; because the accumulator has not then sufficient extent of fall to produce the combination of a blow

with a dead pressure which has been found so effective and essential in riveting, especially for the heavier class of boilers.

An example of the Stationary Hydraulic Riveter on this plan is shown in Fig. 1, Plate 51, which represents a machine of the largest size, that is now at work riveting large marine boilers at Messrs. Palmer's, Newcastle-on-Tyne. The riveter A is here shown riveting a large high-pressure marine boiler B, 12 ft. diameter and 11 ft. high, with $1\frac{1}{8}$ in. plates; this is received in a pit C, in which the riveter is also more than half sunk, so that only an ordinary height of machine of about 5 ft. is above the ground line D. This arrangement saves head room in the shop, and a platform and ladder E beneath the traveller give easy access to the die on the holder-up F; but no person is required to be inside when the machine is working, as the rivets are put in from the outside. By means of this machine the boiler can be riveted straight off when plated.

As there is a quantity of boiler work that can be done best by taking the riveter to it, or cannot conveniently be done by any form of fixed riveting machine, the arrangement shown in Fig. 2, Plate 52, is used in such cases, consisting of a Portable Hydraulic Riveter, carried upon a bracket or column, and balanced. This is shown in the drawing applied to rivet together the flanged rings of the internal flue A of a boiler. For this class of work the portable riveter B has a shoe C cast on the cylinder, which works vertically up and down upon the slipper-guide on the casting D attached to a column or wall E. The riveter is not quite balanced by the weight F attached to the lever G, which works on a centre H in the bracket D; and this centre is the only fixed connection between the portable riveter and the bracket. The riveter being slightly heavier, all that the man has to do to clear the rivet head is to exert a lifting pressure equal to the difference between the weight of the riveter and the balance weight acting through the lever; this dispenses with the necessity which at present exists of lowering the whole tube to clear the rivet head. The man then releasing his hold of the machine, it falls with the cupping die on the rivet head; and water being admitted under the ram J, the lever K rises and

closes the rivet, without any jerking of the tube or any vibration or strain upon the crane chains. This arrangement takes up no shop room, since the greater part may be embedded in the wall; and it is equally suitable for riveting the front end on a boiler, when the end is attached to the shell by an outside angle-iron. This machine has a cylinder 6 in. diameter, and effectually accomplishes the small residue of work left undone by the fixed riveting machine; and as a rule it involves little extra cost for accumulator and pumps.

The extended adoption of high-pressure hydraulic tools at many works where hydraulic power is already in use up to the ordinary pressure of 700 lb. per sq. in., or where the low pressure of the waterworks mains is used, has rendered necessary some simple means of converting the existing pressure into the higher one required for any special tool or machine. Such an apparatus is shown in the Intensifying Accumulator, Fig. 10, Plate 58, in which the pipe A conveys the low-pressure water into the cylinder B, and the pressure on the piston C acting upon the smaller ram D gives an increased pressure to the water in the second cylinder E in proportion to the relative areas of the piston C and ram D. In this case the piston is 19 in. diameter and the ram $3\frac{3}{4}$ in., and a pressure of 60 lb. per sq. in. on the piston gives 1540 lb. per sq. in. on the ram. The water from the pumps enters through the inlet G, and passes out at H to the machine to be worked by it; no water is consumed from the low-pressure cylinder, but it is simply driven back by the force pumps into the low-pressure accumulator or mains.

In Fig. 3, Plate 53, is shown the general arrangement of the Hydraulic Riveting Plant used on a large girder bridge carrying Primrose Street over the metropolitan extension of the Great Eastern Railway; and the experience of its working has been so successful that similar plant is being constructed for riveting the greater portion of the large roof at the extension station. The furnace A both heats the rivets and raises all the steam required by the boiler B to drive the engine C, which works the pumps D; these force the water into the

accumulator E, whence it is transmitted through the pipe F to the riveter, and is returned after use to the tank G. There is all the necessary gearing for traversing, swinging, hoisting, and altering radius of jib; and the crane is also arranged to lift any weight up to about 1 ton. Thus it not only rivets up, but also assists in the construction of the bridge. This riveting machine has put in at the Primrose Street bridge 300 $\frac{3}{4}$-in. rivets per hour, and 120 to 150 1-in. rivets per hour, through eight thicknesses of $\frac{1}{2}$ in. plate. Punching and shearing machines are combined with it when required, and are found very convenient. From the experience of the working of this machine, though only on its first trial, the writer has come to the conclusion that one set of hand riveters in addition to the machine will do the work of six sets without it; and for the heavy work especially, will do it much better. The rivets most difficult to be got at are not generally of the greatest importance, and a judicious combination of hand and machine work would in the writer's opinion very considerably reduce the cost and lessen the weight of bridge work, more especially if oval rivets were used; and the closing of these can be best done by hydraulic pressure. For many suggestions as to this application the writer is indebted to the late Mr. G. H. Ashbee.

In Fig. 4, Plate 54, is shown a proposed arrangement for doing work on bridges &c. in situations difficult of access or up-country places, where the cost and difficulty of transporting the heavy weights required for ordinary accumulators would be too great. A light galvanised tank A is placed at any convenient elevation, fixed on any adjacent building or height; and the pipe B conveys water from the tank to the large piston of the intensifying accumulator C; the high pressure is obtained by pumping water from the pump D into the small end E of the accumulator, whence it is taken by a high-pressure pipe F to the riveter G or other machines on the ground. The pumps are driven by an ordinary portable engine, or can be attached by gearing to a gin worked by cattle. The accumulator itself is on wheels for the convenience of transport. As there is no consumption of water from the low-pressure tank, a very much smaller tank than would at first

appear necessary is required; for assuming that only 20 lb. per sq. in. is obtained on the low-pressure side, an elevation of a little over 40 ft. will give this pressure, and the tank once filled requires no refilling, as there is no loss except that due to evaporation and any slight leakage; consequently a tank of only $4\frac{1}{2}$ cub. ft. capacity will keep a 6 in. portable riveter in full work using a pressure of 1500 lb. per sq. in.

In extending the application of hydraulic power, the next thing after the application to riveting was to do away with the skilled labour required in the flanging and bending of plates. This is not easy to accomplish, and after long continued trials the writer has found that flanging by solid dies has many disadvantages and involves great cost in dies and moulds; and he has come to the conclusion that the plan of hydraulic flanging press with a hollow ring die, by M. Gustave Piedbœuf of Jupille near Liège, is the best adapted for this purpose.

In Fig. 5, Plate 55, is shown a sectional elevation of this Hydraulic Flanging Machine. The cylinder A is connected to an accumulator loaded to about 1500 lb. per sq. in., and the water acting on the ram B raises the moving table C, carrying with it the matrix or annular die D, which is supported on small columns E; some of these are not bolted to the table, but only slipped in, and can thus be easily taken out when the plate P has been flanged and requires to be removed. The block G is attached to the top frame, and corresponds to the matrix; and although in this example a round plate is shown, the block and matrix can be made to any required shape. The small auxiliary cylinders H carry on their rams a table K, suitable openings being made in the main table C to allow of the rams H moving freely up and down independently. The full black line in the drawing shows a plate P at the moment before completion; and the dotted lines show it just completed and detached from the block G, and ready to be removed by taking out one of the columns E. To flange a plate after heating it, the main table C and small table K are let down to their bottom position; and the plate being placed on the table K,

pressure is admitted to the cylinders H, causing this table to rise up and hold the plate against the block G; this prevents all buckling and risk of unequal flanging. Pressure is then admitted to the main cylinder A, causing the main table C carrying the matrix D to rise; the matrix catches the edge of the plate P and forces it over the block G, as shown. The water is then let out of the cylinders, and the plate is done, the whole operation occupying only about half a minute.

In Figs. 6 and 7, Plate 56, is shown an application of hydraulic pressure to a machine for Shearing Chain Cables, for cutting into scrap or for taking out links in testing &c. Shearing by hydraulic pressure is not new, but this design has some novel features. One of the conditions being that the cable is to be cut in one stroke, this is accomplished, not indeed at one moment of time, but by stepping the knife A, which allows the area of the cylinder to be halved, at the same time doubling the stroke although using the same amount of water. The pressure employed being as much as 2000 lb. per sq. in., this reduction of diameter is a great consideration towards obtaining a strong cylinder with a moderate quantity of metal. The drawback gear B is also hydraulic, and the machines have two ends, so that every intermediate size of cable from $3\frac{1}{2}$ to $\frac{1}{2}$ in. can be cut without changing the knives or injuring an unnecessary number of adjoining links. Several of these machines are working in public testing establishments in this country.

In Figs. 8 and 9, Plates 57 and 58, is shown one of the writer's Hydraulic Punching Shearing and Angle-Bar Cutting machines, which dispenses with belting and gearing. This machine consists of three parts, each of which can be used independently of the others, and can be placed in different parts of the yard if desired. A is for angle and bar cutting, B for shearing, forging, and stamping, and C for punching. The inlet and exhaust valves V are worked by hand from above or at the side, or by a treadle on the ground under the foot of the attendant; E, H and P represent the exhaust pipes, the pressure pipes to the drawback gear, and the inlet pipes from the main. Suitable provision is made to prevent the rams from coming too far down; and the stroke can be regulated to a

nicety, so as to waste no power when cutting or punching thinner plates. This is a valuable point, and as the entire movement and stopping or starting of the machine is in the hands of the attendant, the risk of blind holes from the punch coming down too soon is obviated. This machine has a 12 in. cylinder, and has punched $1\frac{1}{2}$ in. holes in 1 in. plates, and sheared $1\frac{1}{2}$ in. plates and angles $5 \times 5 \times \frac{1}{2}$ in. As a speed of over 30 strokes per min. can be obtained, there is no difficulty in punching holes as fast as is possible by men continuously, which is supposed to be about 20 to 22 per min. No breakdown of the machine is likely to occur, since if too heavy a cut or punching is attempted the ram stops as soon as the accumulator pressure is reached ; and if one should break down, the others are not affected as in geared machines. The object of making these machines of such large power is to enable dies and punches to be attached for punching large openings in thin plates, and for stamping and moulding; hence all the dies and knife holders are so made as to be readily detached, and the necessary moulds applied for forging and stamping. The knives can be placed at any angle, slots being provided in the dies for allowing them to be turned round.

The Hydraulic Corrugating Press shown in Figs. 11 and 12, Plate 59, is employed to corrugate sheet iron for roofing purposes, and to stamp fence pillars and posts; it corrugates plates 12 ft. long and from $\frac{1}{16}$ to $\frac{1}{4}$ in. thick, and would do larger sizes. The bedplate A carries four columns B, which support the end frames or girders C. The rams D are parts of these; and the cylinders E which move up and down on the rams are attached to the cross girder G, to the underside of which is fastened the corrugating die H; the bottom die K is secured to the bedplate A. The sheet J to be corrugated is passed through the dies, and the pressure put on each time it is advanced; after the first corrugation, no guide is required, as the corrugations themselves perform that office. This machine by a very simple modification would form an effective plate-shears for ironworks, and designs by the writer for this purpose are under the consideration of some ironmasters who have expressed a favourable opinion respecting them.

In the application of hydraulic power to machinery, however well it may be adapted for tools having a reciprocating motion, hydraulic motors have generally been considered not so suitable or applicable for driving machines with a rotary motion. But in Brotherhood's Three-Cylinder Hydraulic Engine, shown in Figs. 13 and 14, Plate 60, all the objections hitherto met with in other attempts have now been successfully obviated. Three cylinders A, always open at their inner ends, are attached to a central chamber B; and a single crank-pin receives the pressure on the three pistons acting through the struts C; the water is admitted and exhausted by means of the valve V, which is rotated by the eccentric pin E; a face view of the valve is shown in Fig. 15. There being no dead centre, the engine will start in any position of the crank-pin, and a perfectly uniform motion of the shaft is obtained without using a flywheel. The pressure being always on the outer end of the pistons, the struts C are always in compression and take up their own wear. The power can be taken off from the engine either by a belt or by gearing, both plans being shown in the diagram; or, as in the case of a capstan, direct from the shaft. The writer's reason for referring to this engine is on account of its applicability to the extended use of water pressure for transmitting power to shop tools, because, owing to the great speed at which it can be run, it will not only save the present loss from friction of gearing for transmission, but also reduce the friction in the machine itself by dispensing with gearing for getting up speed.

The application of hydraulic power to machinery has been carried out in a very complete manner by the writer at some extensive iron and corrugating works, the engineer of which, Mr. E. J. C. Welch, has enabled him to make a series of experiments for ascertaining the economical results of the use of hydraulic power as compared with steam power; and the writer takes this opportunity of acknowledging the value of his assistance. Previous to the adoption of the hydraulic corrugator and other hydraulic tools that have been described, these works were driven by a horizontal steam engine having a cylinder 18 in. diameter and 3 ft. stroke, which

drove shafting through gearing in the usual way. The corrugating was done by falling weights raised up by cams and let fall in guillotine fashion upon the sheets, causing much vibration and nuisance to neighbours, and involving the objection of the machine often breaking down. Two single-acting force pumps of 3 in. diameter and 12 in. stroke, attached to the engine, are employed to pump water into the accumulator, which has a ram 7 in. diameter and 12 ft. stroke, and was loaded in the first instance to 2300 lb. per sq. in. Pressure pipes lead from the accumulator to the various machines situated in different parts of the works, comprising a hydraulic punch and shears, two of the hydraulic corrugating presses, and a portable hydraulic riveter. A hydraulic crane is about to be erected near the corrugating presses to take away the sheets when corrugated; and a three-cylinder hydraulic engine is proposed to be put up for transmitting motion to shafting. The exhaust water passes through return pipes to the tank from which the pumps draw, and is used again.

With the object of obtaining some definite results in regard to the economy of hydraulic transmission of power as compared with steam, an extensive series of indicator diagrams were taken by the writer from the engine driving these works, and numerous experiments were made as to the power required for the punching and shearing machines &c. The results obtained are however not so definite as was desired, in consequence of the great variations in the quality of the iron used in the trials, which caused conflicting results. It has consequently been determined to make a further series of experiments with the different sizes of iron of uniform quality.

As to the power saved by hydraulic transmission the following result was obtained. The indicated horse power of the engine at 50 rev. per min. was

6·65 Ind. H. P. when driving the transmitting shafting alone,
3·51 Ind. H. P. when running light without the shafting,

leaving 3·14 Ind. H. P. as the power required for the transmitting shafting of about 300 ft. length. This shows that when running

without doing work 47 per cent. of the engine power was spent in transmission by the shafting; and a further loss has to be added for the friction of the gearing employed in getting up or reducing the speed of the several tools.

In the hydraulic transmission of power, on the contrary, the loss of useful effect between the pumps and the accumulator is very little at the usual speed of working; for with one pump working, 1694 cub. in. was the theoretical delivery of the pump for 20 strokes, and 1614 cub. in. was the actual quantity pumped into the accumulator, showing a loss of only $4\frac{3}{4}$ per cent.; and with both pumps working, the corresponding quantities for 20 strokes were 3388 and 3278 cub. in., showing a loss of only $3\frac{1}{4}$ per cent. These experiments were carefully made, the accumulator registering the exact distance it travelled for a certain number of strokes of the pump.

The loss from friction in the accumulator was found to be as follows:—

1250 lb. per sq. in. was the ascending pressure in the accumulator
1225 lb. per sq. in. „ descending „ „

therefore, as in ascending the friction has to be overcome by the pump in addition to lifting the load, and in descending the friction has to be overcome by the load itself, the amount of the friction will be half the difference of pressure in the two cases, or $12\frac{1}{2}$ lb. per sq. in., being only 1 per cent. of the power. This result applies equally to the friction in each of the hydraulic machines; and as the power is generally applied to the cutting tools direct from the ram, 2 per cent. represents all the loss from friction; and there remains only to add the loss due to the friction of the water in the pipes, which cannot amount to much if proper care is taken in proportioning their area and in avoiding bends.

In conclusion the writer wishes to express his obligations to Mr. James Platt of Gloucester, who, as the maker for him of nearly all the special hydraulic machines described in the paper, has by his expenditure of labour, time, and skill, contributed greatly to the development of the system; and to Mr. Edward

Wilson for first affording him an opportunity for applying the portable riveting plant to bridge work on a complete scale.

Mr. Tweddell exhibited sectional specimens of riveting through several thicknesses of plate done by the hydraulic riveter, and planed down to the centre line of the rivets, showing the complete manner in which all the holes were filled by the rivets. He showed also a working model of the three-cylinder hydraulic capstan engine.

Mr. D. Adamson considered they were much indebted to the author of the paper for the very complete way in which he had laid before them the particulars of the applications already made of hydraulic power; and there were many points referred to in the paper which he was sure would be found useful in various manufacturing operations. For his own part however he was not impressed with the importance of the application of hydraulic power to ordinary riveted structures; and as expressed at a former meeting he had an unfavourable opinion respecting the application of hydraulic power to riveting machines, on the ground that it necessarily involved the consumption of twelve or thirteen times as much power as would be used in doing the same work by a machine driven by rotary action through direct mechanical connections. For instance, in a hydraulic riveting machine having a stroke of 4 in., the work to be performed was all confined to the last $\frac{1}{4}$ in. of the stroke; and supposing the total pressure on the riveting die amounted to 25 tons, this large amount of force had to be exerted throughout the whole length of the stroke of 4 in., though producing a useful effect only during the last $\frac{1}{4}$ in. In the steelyard riveting machine that he had mentioned at the former meeting, not only was the whole of the

power expended usefully upon the work, but at the same time the means was obtained of registering with exactness the force expended, and it was taken out of the power of the attendant working the machine to put a single pound more pressure or less pressure upon the work than the machine was adjusted for. Hence he considered this registering steelyard riveter could not be equalled by any other description of riveting machine either in the quality or in the economy of the work performed by it.

The subject of actuating workshop tools by hydraulic power had early been considered, he believed, at the works of Sir Wm. Armstrong, and it was found that in the case of a planing machine such a mode of driving would be very disadvantageous. The maximum force required in one part of the traverse might be 1000 lbs. pressure, and in another part only 100 lbs.; and if in some parts of the traverse only one tenth the force was needed that was being constantly expended, it was a most extravagant expenditure, and such as he considered should never be permitted in mechanical operations of that sort. In respect of portability however and adaptability to shipbuilding and other special classes of work, the transmission of power by hydraulic pressure certainly appeared a very suitable arrangement. Also for dealing with the very thick plates now used in high-pressure marine boilers the hydraulic riveter was excellently suited; and in the case of riveting together a number of thicknesses of plate for bridge work, as in the sectional specimen exhibited, where the proportion of useless expenditure of force in the earlier part of the stroke was less, and where it was necessary to compress the whole of the plates together by the high pressure of an accumulator, the hydraulic riveting machine might be advantageously used, because it would then be doing a larger amount of useful work than where the whole consisted in only forming the rivet itself in the concluding portion of a long stroke, as in riveting boilers and other ordinary riveted structures.

He had not had a large experience in other modes of producing rotary motion, but was decidedly in favour of shafting and simple leather belts; for whether it was an ordinary pulley in a machine

shop or a belly-helve in a forge that had to be driven, the belt transmitted back to the engine the exact amount of resistance offered by the work executed, and there was then no loss by the expenditure of a needlessly large amount of power from an accumulator. In connection both with the employment of hydraulic pressure and with the steam hammer it appeared to him that engineers were a little liable to be too much taken up with one idea alone, and were consequently led sometimes into expending a great deal of power for little work done. For instance, the old-fashioned belly-helve when lifted to its proper height would yield the maximum force from the power expended in lifting it; but with the steam hammer, in order to get a stroke of 4 ft. to hammer a shaft or ingot 12 in. diameter, steam had to be used the full length of the stroke while the blow was only equal to a 3 ft. fall; and hence a direct loss of 25 per cent. of power. No doubt a steam hammer was a very manageable tool, but it could not be called an economical machine in giving out force in proportion to the power expended to produce it. Similarly the system of hydraulic power might he thought be carried to an extreme, and was then apt to distract attention from the question of economy in working. On the other hand, for such operations as those described at the Paris meeting of the Institution in M. Tresca's elaborate paper on the "Flow of Solids" (Proceedings Inst. M. E. 1867 page 114), in which not only was lead forced through dies by hydraulic pressure, but even wrought iron when hot enough to be sufficiently plastic was subjected to identically the same treatment, hydraulic pressure was unquestionably a highly valuable agency, most appropriate for the work to be done and most economical in its action. There were many applications in which extreme force was required, where by no other mechanical means could the same work be done so efficiently, or probably so economically, as by hydraulic pressure.

The hydraulic flanging press described in the paper, which appeared a very practicable arrangement, was likely he thought to prove serviceable for flanging irregular forms, and also the internal flanges upon circular plates, where the metal had to undergo

compression in forming the flange; but for regular forms, such as cylindrical boiler flues or rings with external flanges, requiring the metal to be gradually elongated in the formation of the flange, his own experience was decidedly in favour of flanging in the ordinary manner by a machine having a rotary action; this he considered preferable to a hydraulic press, both on account of the greater expedition with which the work was done, and also in respect of economy of power. With a machine of this class in constant use at his own works a flange 3 in. deep was put upon a 7-16ths in. plate of 3 ft. diameter in from 25 to 30 seconds, the plate to be flanged being driven at 60 revolutions per minute. He should be happy to afford an opportunity at his works for a comparative trial of the rotary flanging machine employed there, so as to compare it with the hydraulic flanging press, in order to ascertain the rapidity with which the work could be performed, and the power required as shown by indicator diagrams.

Mr. P. G. B. Westmacott observed that in connection with the subject of hydraulic power there was a wide field for the exercise of ingenuity and skill; and he was sure they must all feel indebted to the author of the paper just read for the information he had given. With regard to hydraulic riveting, he remembered many years ago that a steam riveter which had been applied by Sir Wm. Armstrong at his works at Elswick had been successfully converted into a hydraulic riveter, and a very decided benefit had been found from the change. One great advantage of hydraulic riveting was that the pressure could be kept on the rivet and the plates held together until the rivet had got rather cool; consequently if there were any buckling in the plates this was prevented from acting on the rivet and disturbing it whilst it was capable of yielding. In an experiment that he had tried with the hydraulic riveter he had succeeded in completing a single-riveted boiler entirely steam-tight by the riveter alone, without touching it with a caulking tool; this was with $\frac{3}{4}$ in. rivets put in at an ordinary pitch. He had seen one of the portable hydraulic riveting machines described in the paper at work on a bridge in London, and had

been so much impressed with its value that he had ordered one for application in a somewhat modified form in the construction of a large swing bridge now making over the river Tyne.

In reference to the remarks just made respecting loss of power in certain applications of hydraulic power, he quite agreed that it would be very inexpedient to employ hydraulic machines for all kinds of mechanical operations; and he considered it was only for particular applications that hydraulic power was suitable. At the same time it was necessary to take into account the loss of power continuously going on in driving the shafting and gearing of machines not worked by hydraulic pressure. In a trial that he had made upon a length of 1200 ft. of shafting averaging $2\frac{3}{4}$ in. diameter, which had been running for some years, he had found that, when the driving belts were all thrown off, the power required to drive the shafting alone at a speed of 120 rev. per min. amounted to as much as 1 Ind. H. P. for every 100 ft. length of shafting. This loss was going on continuously, whether the whole of the machinery was being driven by the shafting or not; and in addition there would be the further loss from the friction of the belts and gearing of the various machines driven. In many cases therefore where machines acted intermittently, instead of running continuously, it seemed to him probable that a hydraulic machine would not only be better adapted for the work to be done, but would also entail less loss of power than a machine driven by shafting.

The hydraulic flanging machine described in the paper afforded certainly a very quick and efficient means of performing the operation of flanging plates; but he had not himself experienced any of the difficulties alluded to in this class of work, and with a simple machine which was constantly used for the purpose at the Elswick Works he had not found any difficulty in bending plates even to as sharp curves as those shown in the drawing.

In reference to the employment of the intensifying accumulator described in the paper, for avoiding the necessity of carrying across country the heavy weights required with an ordinary accumulator, he enquired whether an air vessel had ever been

applied for working a portable hydraulic riveter. In special cases of that kind he thought an air vessel would be adapted for isolated situations; in the experience he had had of air vessels working under high pressure he had found no difficulty in their application. At the present time he had air vessels working at a pressure of 850 lb. per sq. in., and supplying a large plant of hydraulic machinery in situations where it had not been found expedient to introduce an accumulator on account of its weight or size.

In the three-cylinder hydraulic engine shown in the drawings he enquired whether the revolving disc-valve was found to work satisfactorily, in the absence of any relief valve for preventing shock from the water at the end of each stroke. Unless the exhaust port in the valve were made long enough to give a little lead, so as to afford a prompt and free exhaust from the cylinders, the valve would be liable to be lifted from its face by the shock of the exhaust water; the lifting of the valve would be objectionable, because any particles of grit in the water would then be apt to get under the valve face and gutter it. He also questioned whether the balancing arrangement would be found efficient in practice.

Mr. H. Chapman observed that, with regard to the pressure employed in the hydraulic riveter, this was not necessarily the same throughout the entire stroke; and it had been mentioned in the paper that by taking advantage of the impulse of the falling accumulator at the end of the stroke a dead pressure of 40 tons was increased to nearly 60 tons at the time of closing the rivet; the machine thus starting with the lower pressure arrived at the higher pressure at the point at which it was required. He had seen a great deal of the hydraulic riveting, and the work was in all cases unexceptionable. At the works of Messrs. Penn, in places where the tapered corners of three thick plates had to be riveted together in marine boiler work, the hydraulic riveters were very conveniently employed; having the riveting dies replaced by dummy dies, these were applied to bring the plates together and hold them so, the plates having been previously warmed by the application of hot

iron blocks. The pressure from the riveter was kept against them until the plates were cold; the dummies were then replaced by dies, and the riveting done, which was perfectly steam-tight at 150 lb. per sq. in. pressure.

It had been mentioned that there were now upwards of a hundred of these hydraulic riveters in use; and he should be glad to hear the experience of some of those who had used them. His own experience of the hydraulic riveters had been so satisfactory that he should certainly have them employed upon all boiler and bridge work with which he might be connected. He enquired whether the cost had been ascertained of putting in a number of rivets by the hydraulic riveter, as compared with the cost of putting in the same number by steam riveting and by hand.

The pressure in the ordinary construction of accumulator being got by weights, he asked whether any attempt had ever been made to reduce the weights, so as to do smaller riveting with a corresponding pressure. As it was impracticable in small shops to have a separate riveting machine for every different thickness of plates to be riveted, he suggested that some such plan would be applicable for that purpose, so as to get a lower pressure for lighter descriptions of work; and it seemed to him a simple matter to arrange.

The question of packing was a point of vital importance in hydraulic machinery, and hemp having been stated by the author of the paper to be pretty generally used by himself, he should be glad to know why it was preferred; and whether leather or metallic or hemp packing was best for a moving piston or for a stationary stuffing-box. Also whether a different packing was required for high and for low pressures, and for different speeds of working.

The hydraulic capstan worked by Brotherhood's three-cylinder engine he had several times seen in regular work in London at the Broad Street goods station of the London and North Western Railway; and on one occasion when it was desired to see the state of the valve, the machine was taken entirely to pieces and put to work again in only 17 minutes, which showed the simplicity of the construction of the machine and the facility

for getting at the valve; this was found to be in perfect condition. If therefore the valve should be found at any time to be worn, it could easily be replaced; and it was not an expensive part to have in duplicate. He enquired what material had been found the best for the valve: whether it was a brass valve working on a cast-iron face, or cast-iron on cast-iron.

Mr. P. Brotherhood replied that hard phosphor-bronze was used for the valve of the hydraulic capstan, and also for the crank-pin bearings. By means of the arrangement of the balance ring at the back of the valve, the area of unbalanced pressure and the consequent pressure per sq. in. on the working face of the valve could be varied as desired; and in the earlier capstans the proportion of the balance ring had been such as to give a pressure of 900 lb. per sq. in. on the working face of the valve; but subsequently the diameter of the balance ring had been increased, and owing to the diminished unbalanced area on the back of the valve the pressure on its working face was thus reduced to 300 lb. per sq. in., under which the valves were found to wear extremely well. It had been found quite unnecessary to provide any relief valve; the length of the exhaust port in the valve was made exactly the same as that of the port in the cylinder face, and there was not found to be any shock whatever from the water in the working of the machine.

The question of packing, which had been alluded to, was one of great importance. In the hydraulic capstans he had used at first deep cupped-leathers for the packing of the pistons and valves, like those shown in the drawing, Fig. 16, Plate 61, but these did not run satisfactorily; he then had bucket leathers made, of shallower section so as to be stiffer in the lip, as shown in Fig. 17, and with the flesh side of the hide outwards; these stood the hardest work at the Broad Street station, where they had already been in use for five months, and others were in use elsewhere, with equal success.

A metallic packing that he had used in other cases with some success consisted of a gunmetal ring I, Fig. 18, which was slit and

tongued in the usual way to allow the requisite elasticity, and for the packing of plungers it was surrounded outside by a continuous india-rubber ring of U section; the flanges of this india-rubber ring were forced outwards and formed a tight joint in the groove in which it lay in the gland, when the water pressure came upon the back of it, and the metallic ring was thus kept compressed upon the plunger. For pistons the reverse arrangement was adopted, as shown in Fig. 19, the india-rubber ring being placed inside the metallic ring, so that the water pressure coming behind it kept the metallic ring pressed outwards against the sides of the cylinder; in double-acting pistons the water pressure was admitted into the interior of the piston through small holes drilled in each face round the circumference and covered by the lips of the india-rubber ring, so that in the upstroke the pressure entered the piston through the holes in the lower face and closed those in the upper face, and the converse in the downstroke, thus preventing leakage through the piston. This construction of metallic packing was only good for clear water; it was apt to cut in dirty water.

The President enquired whether there was any motion upon the india-rubber ring in that arrangement of packing; and whether there was not considerable friction, as it appeared the moving surfaces were under the full pressure of the water acting on the back of the packing.

Mr. P. Brotherhood replied that the friction was considerable on that account; but he used this packing to a great extent and found it very convenient, because it had the advantage of being self-acting and requiring no attention. The india-rubber ring lay passive without any motion, the metallic ring being held endways in a groove in the gland or piston.

The cast-iron connecting-rods or struts for the three cylinders of the hydraulic capstan were made in a very simple manner by casting the three together in one piece, boring them for the crank pin, and then breaking them apart, after which the ends only required rounding with a file, without any expensive fitting.

Mr. J. Ramsbottom observed that many ingenious arrangements of hydraulic machinery were described in the interesting and suggestive paper now read, and there were several points in it which might be attended to with great profit, especially in respect to the economical use of fuel. For certain classes of work he agreed with the opinion which had been expressed that there was a great loss of power in the use of hydraulic pressure as compared with ordinary shafting; where shafting could be continuously employed for driving shop tools, it must necessarily be preferred to hydraulic power. But the case was reversed where the power was required to be used at variable intervals of time and at a distance from the prime mover; and hydraulic arrangements might then be employed with great advantage. For such tools as planing or slotting machines however he did not think hydraulic power could be either theoretically or practically advantageous, on account of the varying resistance encountered by the tool at different points in the same cut; there were places where the resistance might be nearly equal to the full force of the hydraulic pressure, and others where it might be not more than one tenth as much, whilst the power would continue uniform, being supplied by the constant pressure of the accumulator. Thus the velocity of the cut would vary greatly in different parts of the work, instead of being kept uniform at the one proper speed required for the particular material operated upon. This difficulty of reducing the pressure so as to meet the work to be done would attend any application of hydraulic power for driving a shop containing a number of machines working simultaneously, since the tools would require some of them the full pressure and others less, while the accumulator would have to be kept always at the full maximum pressure. The conclusion he came to therefore was that there was much to be said on both sides as regarded the mode of driving by rotating shafts or by hydraulic power. The practical success of the hydraulic system as applied to cases where large amounts of force were required to be exerted at remote distances from the prime mover was abundantly evident from the experience of Sir Wm. Armstrong's arrangements in this branch of mechanical engineering; and if the system had not

been radically sound in these applications, it could not have continued so successful to the present time. It was possible however to push any good idea too far, and by looking too exclusively in one direction to get misled and to make misapplications of a sound principle.

The three-cylinder hydraulic engine was a very ingenious machine; and he did not see that there could be any practical objection on account of shock from the water, owing to the nature of the valve employed, which was not reciprocating, but rotated with great velocity, especially in relation to the velocity of the piston at the moment when the port was being opened. Any relief required beyond that afforded by the valve would be met by the small quantity of air which water ordinarily contained, and by the elasticity of the working parts &c. Even if there had been any shock, he did not consider it would have been found to occasion any practical difficulty, as none of the working parts would be forced out of place by it.

Mr. E. A. Cowper remarked that the use of hydraulic power was a subject which had engaged his attention for many years; and he remembered long ago, before the accumulator was invented, hearing of a range of hydraulic presses at a paper mill, one of which was loaded with pig iron and served as a reservoir of power for working the other presses; when any one of these presses was required to be brought into action, a valve was turned and the press was run up by running this reservoir down. Subsequently at Messrs. Fox and Henderson's works twenty-seven years ago he had applied hydraulic presses for working iron, and had a hydraulic reservoir having a large ram at top and a small one below, to which the weight was hung for working the presses. One of the operations performed by this means consisted in cutting out the links for suspension bridges, with the oval end and slot end for adjustment 1 ft. 4 in. across; each link was $7\frac{1}{2}$ ft. long, 10 in. wide in the body, and 1 in. thick, and was cut complete out of the solid hot plate in a press having two 9 in. rams; the process was quite satisfactory and a most convenient mode of

working. With the packing leathers he had had no trouble, inasmuch as they were good leathers, nicely applied in the first instance. These machines gave no trouble, and their use was extended to many different operations, including the shaping of large quantities of spokes, cutting out axleguards, and a variety of forgings and weldings. In connection with this subject of dealing with iron by pressure, instead of by blows, he might mention that the plan of welding tyres with a butt joint was introduced at that time, by bringing the ends together while they were in the fire by means of a screw clamp, the welding being thus completed very effectively without any hammering.

With a heavily loaded accumulator of relatively small capacity it had been mentioned that a much heavier pressure was obtained at the end of the fall, giving something of the effect of a blow upon the work; and thus although the falling weight might not be doing its full work in the earlier part of its fall, the effect of the fall was not altogether lost, but was transformed into an increased final pressure. For general use however he should prefer a steady pressure from the accumulator, without anything of a blow from the momentum of the descending weight.

With regard to the circular disc-valve of the hydraulic capstan, he did not consider there was any necessity to provide a relief valve for preventing shock from the water; he had not employed a relief valve in any hydraulic machines, and had not found it necessary to do so. It was only requisite that a slide-valve should remain open to the exhaust until the moment when the piston arrived at the extreme end of its stroke, and the port could be reduced in size by notching it or making it diagonal; and as the valve was at that time moving with its greatest velocity, while the piston was just starting from a state of rest, the valve opened the admission port quicker than the piston could take the water; and for the same reason an ample exhaust opening was maintained until the very end of the stroke, thereby preventing the occurrence of any shock from the water.

The plan introduced by Mr. Webb of using oval rivets in special situations seemed a very good one, provided care were

always taken to put the rivets in the proper direction, edgeways to the strain; and he wished to know what increase of strength was found to be obtained by that plan, or what percentage of saving in the number of rivets required.

Mr. J. Platt, alluding to the alleged great loss of power in the hydraulic riveting machine in consequence of its utilising only about one twelfth of the whole power expended, whilst in a rotary machine all the power was utilised, observed that he differed altogether from that statement of the case; the rotary machine he supposed required rather a heavy flywheel for the purpose of storing up the power for use at the moment it was wanted, and considerable power would be absorbed in keeping up the momentum of that wheel, which had to be kept in motion whether the rivets were being closed or not. With regard to the steelyard arrangement for adjusting the closing pressure according to the size of the rivet, the same provision was made in the hydraulic riveter by adjusting the weight upon the accumulator, and the full accumulator pressure was exerted upon every rivet. For obtaining the advantage of the momentum of a falling weight, the area of the accumulator ram was so proportioned as to give a fall of 12 in. for putting in each rivet; and it was then found that the momentum of the falling weight gave the advantage of an increase of 25 per cent. in the closing pressure upon the rivet, above the pressure to which the accumulator was loaded. In working with an accumulator not so proportioned as to give this advantage of momentum, there was no doubt considerable loss of power in moving the riveting die through some four-fifths of its stroke under the full pressure before it touched the rivet; and it would be quite practicable to obviate this by using a lower pressure from a separate source during the first part of the stroke. But in ordinary practice what was wanted was to reduce the riveter to as simple a machine as possible, in which there was consequently less leakage, though some sacrifice of power.

The hydraulic flanging press described in the paper he had seen at work in Prussia, and it did its work very well. The parabolic

curve given to the matrix turned the edges of the plate in very gradually all round, and as true as could possibly be required; the advantage over a square die was not only that the flange was bent more gradually by the curved matrix, but also that in consequence of the matrix being made in the form of an open ring, there was no difficulty in getting the finished plate off the block, as the open matrix left it free to drop off the block immediately upon the completion of the flanging.

Mr. P. R. Jackson mentioned that some years ago, having to construct a hydraulic press cylinder of extra size and strength, he had designed a method of avoiding the unsoundness to which large thick cast hydraulic cylinders were liable, by employing a very thin shell or cylinder cast of close and rather hard iron, which might be lined or not with copper or brass, rendering it very water-tight under heavy pressures; this thin shell was hooped with wrought iron or steel, sometimes two or three sets of hoops being placed one over another to give the requisite strength. One press which he made forty years ago on that plan was over 21 in. diameter, and was still at work. That method of constructing hydraulic cylinders was at the time considered a great step in advance; now small cylinders could be cast of steel, but for large sizes it was still found advisable to hoop them with steel or wrought iron. The method of driving machinery by hydraulic power he considered an expensive one, and it could only be profitably employed in exceptional cases. He thought the information given in the paper was valuable, and there was a great deal to be learnt from it.

Mr. D. Greig observed that for a portable riveter there was of course a considerable advantage in using a high pressure of water, so as to reduce the machine to a convenient size that could be easily carried about. But for a stationary riveting machine in a shop a lower pressure would have to be employed, such as it would be practicable to carry all over the shop; and he enquired whether the larger size of ram then requisite for working the riveter with this lower pressure would be attended with any disadvantages.

In the flanging machine described in the paper, he did not see any advantage in the open ring die shown in the drawing, as compared with an ordinary solid die, provided the edges of the die were made of the same curved form in each case. He had found very little difficulty in flanging plates by pressure with solid dies, or in getting them off the block again after flanging.

The use of leathers for the packing of the hydraulic riveting machines had in his own experience been attended with some trouble and expense; he had found hemp packing the best for the purpose, and now used it in all hydraulic machinery he had at work.

Mr. Benjamin Walker referred to the statement made in the paper, that in the experiment tried for ascertaining the friction of shafting this had been found to amount to as much as 47 per cent. of the whole power of the engine when running without doing any work; and he enquired what percentage that would be of the gross power ordinarily exerted by the engine when doing work. He mentioned that sixteen years ago, in connection with machinery for driving the extensive flax mills of Messrs. Marshall in Leeds, where there were thousands of belts and loose pulleys, he had taken the opportunity of ascertaining by experiment the exact amount of power absorbed by the friction of the shafting, and had found that it took less than 2 lb. per sq. in. pressure on the piston to drive the shafting and belts alone, the mean pressure being about 20 lb. per sq. in. when the engine was driving the machinery in ordinary work; the engine was a new one, and the boiler was worked at a pressure of 40 lb. The friction of the shafting was thus less than 10 per cent. of the whole power of the engine in ordinary work. On trying the same experiment at Mr. Gott's woollen mill in Leeds, where there was a common wagon boiler working at only 5 lb. pressure, the result was found to be about the same percentage.

While fully concurring in the remarks that had been made as to the considerations limiting the applicability of hydraulic pressure, he hoped the writer of the paper would persevere in his endeavours to extend the applications of that power, and that others also would make trials of it; any defects in the system

would thus be brought to light, remedies would be suggested, and the experience so gained could not fail to be profitable.

Reference having been made to the use of the old-fashioned belly-helve in comparison with the modern steam hammer, he remembered many years ago, at some ironworks then newly erected, the prejudice that existed in favour of the old belly-helve was so strong as to lead to the complete exclusion of steam hammers at the starting of the works; it was even believed to be impossible to make good iron without a belly-helve. Subsequently however a steam hammer was admitted, and afterwards others were added, until ultimately the belly-helves were altogether abandoned ; it was found that equally good iron was made under the steam hammer, and also the iron could be more easily worked by this means, and less skill was required. The practical reason of its superiority was that the work could be so much more easily dealt with than under the old helve.

With regard to the intensifying accumulator described in the paper, he mentioned that there were in Leeds a number of woollen warehouses in which a great many hydraulic presses were employed for packing the goods; and in order to do away with the labour of pumping these presses up by hand, as had previously been the case, he had introduced a contrivance for using the waterworks pressure of about 40 to 70 lb. per sq. in. to give a pressure of as much as 2,500 lb. per sq. in. The town pressure was admitted into a cylinder having a ram of 14 in. diameter and 3 ft. stroke, which acted upon another ram of only $1\frac{5}{8}$ in. diameter, this difference of area giving the required increase of pressure. The higher pressure was admitted to any of the hydraulic presses by simply turning a tap, and the result was very satisfactory in the facility of working the presses without hand labour.

Mr. J. Richardson said that at Messrs. Robey's works at Lincoln he had had a couple of the hydraulic riveters in use for two years, driven by one accumulator, and had found the economy was very considerable in comparison with hand labour; the work was done at not more than one third of the cost of hand riveting, and what

was of much more importance it was found to be much sounder done, as there was no temptation to overheat the rivets; it was a rare thing to have one broken, and the amount of caulking required was very slight indeed. He had not had the means of making a comparison with steam riveting; but before purchasing the hydraulic machines he had examined several steam riveters, and was convinced the hydraulic plan was preferable.

For obtaining the effect of a blow from the momentum of the falling weight in the accumulator, the size of the accumulator and the length of stroke of the riveting dies were so arranged as to get 18 in. fall of the weight for each rivet, thus giving a much greater terminal pressure upon the rivet head than was obtained in any other part of the stroke; and he considered it preferable to use a comparatively light weight with considerable fall, so as to get a lower dead pressure in the early portion of the stroke of the riveting die, and a heavier blow in closing the rivet.

With respect to the use of leather or hemp or metallic packing for hydraulic machines, he had had considerable trouble at first with the ordinary cupped-leathers fitted in the accumulator working the hydraulic riveters, on account of having to use water that was impregnated with lime and sand. The leathers were found to get cut away very quickly indeed, seldom lasting more than two days, while sometimes two leathers a day were used, and it was very well if a leather ever lasted so long as a week. Hemp packing was then recommended by the makers of the machinery; and in other instances in which he had used hemp packing for hydraulic machines he had found less trouble and better results with it than with leather. But before taking the trouble to change the cupped-leather in the accumulator for hemp packing, he had determined to try some means of preventing the excessive wear of the leathers, which was attributed to the dirty water getting in between the leather and the ram, as it was noticed that a slight leakage took place just when the accumulator started to lift and when consequently the pressure had just been off the leather. The accumulator being employed for the riveters alone, and being charged by a pair of force pumps which were kept constantly at

work, had been at first so arranged that on reaching the top of its stroke it closed the suction valve of the pumps; these continuing to work became partially charged with air, and when the riveter started working, about four rivets brought the accumulator down on the bottom stops, often before the pumps had got so far rid of the air as to start lifting the accumulator again. When thus resting on the stops, all pressure was of course taken off the leather of the accumulator ram, and it was just when the accumulator started to lift again that the leakage took place; and this occurred many times in a day. If the water could be prevented from thus getting between the leather and the ram, it was hoped the leather packing could continue to be used, as it was the simplest and most convenient kind of packing for the accumulator. Wedge-shaped india-rubber bands were first tried, slipped over the inner flange of the cupped-leather so as to keep it always pressed against the ram all round; and the leather was then found to wear twice as long. Afterwards hemp was wedged into the annular groove of the cupped-leather, so as to press it still tighter on the ram, and the leathers were thereby made to wear still longer. The expedient ultimately adopted was to put a relief valve on the delivery pipe between the pumps and the accumulator, and to leave the suction valve always open, the relief valve lifting whenever the accumulator ram reached the top of its stroke; the pumps being then always charged with water, the accumulator was never able to get down to the stops at bottom, and consequently the pressure was never taken off the leather. The mischief having previously been done by the sand getting in between the leather and the ram, this plan of maintaining a constant pressure upon the leather proved a complete remedy; and he thought if it had been tried in other cases, instead of having recourse to metallic or hemp packing, the use of leather might have been continued. Instead of the leathers in the accumulator lasting only two days, he had now had them last as long as sixteen weeks; but for security they were changed regularly every three months, and he never had any trouble now from the leathers giving way. The ram of the accumulator in which the leathers were working was cased with gunmetal.

Mr. E. A. Cowper enquired whether there was any iron in the water. That always injured leathers very quickly, because it combined with the tannic acid in the leather, and formed ink.

Mr. J. Richardson believed the water must contain iron, because it was found to make the leathers black and hard. This was not of much consequence however, as it did not prevent them from lasting in the accumulator sixteen weeks or upwards, which was long enough to be quite satisfactory. The leathers on the rams of the riveters lasted from eighteen to twenty months, the motion and consequent wear in that case being extremely limited. The same water was used over and over again, so as to avoid bringing in any more sand than that introduced at the outset; there was of course a slight leakage, which had to be made up, but it was very small indeed.

Mr. D. Campbell, referring to the use of leathers for packing and the means of keeping them tight with little friction, mentioned that in some hydraulic presses for expressing oil, with which he had had to do in India many years ago, and more recently in some presses for packing cotton, oil had been used instead of water, and when the cast-iron rams began to get worn they were cased with gunmetal to prevent them from tearing the leathers; by this means the leathers had been made to last as much as two years, and at the same time the friction was considerably reduced. In these presses however, as it was only through a comparatively short length at the end of the stroke that the heavy pressure and consequent wear upon the rams took place, the gunmetal casing was not required to extend more than a short length, about 2 ft. in the cotton presses, forming a shoe or thimble upon the end of the ram. For rams of 11 to 13 in. diameter the gunmetal shoe was made about 1 in. thick.

Mr. T. Wrightson referred to the very interesting experiment named in the paper for ascertaining by means of a pressure gauge the friction in the gland of the accumulator, the gauge indicating a

pressure of 1250 lb. per sq. in. when the ram was ascending, and 1225 lb. during its descent; and he enquired what was the diameter of the ram in that case, and the kind of packing used, and also whether the velocity of the ram in descending was the same as in rising. These were all three very important elements in the experiment.

Mr. TWEDDELL replied respecting the comparative efficiency of the hydraulic flanging press described in the paper and the rotary flanging machine which had been referred to, that the hydraulic press was admitted to be the best for irregular shapes; and for ordinary flanging also he considered it would be found the most advantageous, because with a rotary machine he understood the flange was liable to be made sometimes of irregular thickness. The advantage of the hydraulic press was indeed more especially seen in the flanging of irregular shapes, such as the front plate of a locomotive firebox, which required to be flanged in opposite directions; this could be completed in the hydraulic machine at two operations, the first forming the circular flange for attachment to the shell of the boiler, and the second then forming the outside flange for riveting to the top and side plates of the firebox. He should gladly avail himself of the opportunity that had been offered for making a practical comparison of the two machines. The object of the inverted form of the press, and of the open ring die or matrix instead of the ordinary form of solid die, was to allow the plate to fall off the block by its own weight and drop through the open die immediately upon the completion of the flanging, before it could have time to contract on the block in cooling. In the ordinary mode of flanging a plate, by placing it on the top of the block, he had always found the contraction caused a difficulty in getting it off the block again; and in the case of flanging some plates in Germany for portable engines he had seen the method tried of constructing the block in segments, with a central cone or wedge which was taken out as soon as the flanging was completed, so as to let the block contract and leave the plate free; but he considered the arrangement of the hydraulic flanging press was decidedly superior.

In reference to the statement made that with the hydraulic riveter a boiler had been completed steam-tight without caulking, he had himself also riveted by that means several portable boilers in Germany, with $\frac{3}{8}$ in. plates and $\frac{5}{8}$ in. rivets, which were never caulked, but were perfectly steam-tight and proved in every respect satisfactory.

In addition to the remarks already made respecting the loss of power attending the application of water pressure in place of shafting for driving machinery, it must be taken into consideration that the pressure pipes which took the place of the revolving shafting were fixed and stationary, entailing no expense for repairs, while all shafting was constantly wearing itself away by friction. As regarded the amount of power required to drive shafting, the result obtained in the trial mentioned by Mr. Westmacott, namely about 1 Ind. H. P. per 100 ft. length of shafting, was about the same as at the Liverpool works referred to in the paper, where the length of shafting driven by the engine was about 300 ft. and was found to absorb 3·14 Ind. H. P.

In applying the portable hydranlic riveter to the swing bridge now in process of construction over the river Tyne, it was proposed by Mr. Westmacott that the main accumulator, situated inside the central pier for moving the bridge itself, should be employed for working the riveter, the pressure in the main accumulator of only 700 lb. per sq. in. being raised by means of an intensifying accumulator to the pressure of 1500 lb. per sq. in. required for working the portable riveter.

The suggestion of substituting an air vessel in place of a dead-weight accumulator was one that had occurred also to himself; but he had not yet carried it out. The plan had however been used for many years by Messrs. Tangye of Birmingham, for small portable hydraulic stamping and forging presses.

In reply to the enquiry about the comparative cost of riveting by the portable hydraulic riveter, he was informed that the average cost of putting in $1\frac{1}{4}$ or $1\frac{3}{8}$ in. rivets through $1\frac{1}{8}$ in. plates by this means was found to be from 3*s.* 6*d.* to 4*s.* 6*d.* per hundred, including the wages of the man working the riveter and also of the

men at the cranes for shifting the work; and this was the general experience in a large number of cases where the hydraulic riveter had now come into regular use. By hand labour the same work could not be done for less than 27*s.* or 30*s.* in the North of England. At some large agricultural engine works $\frac{5}{8}$ in. rivets were being put in at 1*s.* to 2*s.* per hundred by the hydraulic riveter; and this he believed was the lowest cost at which such work could be done. In comparison with steam riveting the saving with the hydraulic riveter was not so great, but was still very large; the riveting of thick plates or of several thicknesses of plate could not be done at all satisfactorily by a steam riveter, but only by hydraulic power. The manufacture of the portable hydraulic riveter had been entrusted to Messrs. Fielding and Platt of Gloucester, whose sole aim had been to perfect the machine to the utmost; and he was glad to take this opportunity of stating how very much he owed to Mr. Platt's assistance throughout. The hydraulic riveting plant that had been employed upon the Primrose Street railway girder in London had since been purchased by Messrs. Cail of Paris; and similar plant had been sent out to other places, where it was now coming into general use. The employment of oval rivets had been suggested by Mr. Webb, but they had at present only been used for some locomotive fireboxes made of steel at Bolton; in that instance the saving effected in thickness of plate by their use was stated to be 20 per cent., but the percentage of saving would of course depend upon the proportions of the oval section.

As regarded packing, he had worked the hydraulic riveters with pressures of 1500 to 2000 lb. per sq. in. with leather packings, and he agreed in preferring gunmetal for the leathers to work upon, wherever the greater expense was not objected to, as he believed the friction of the leather upon gunmetal was rather less than upon iron, but of this he was not certain. A preference had been expressed for metallic packing, provided perfect cleanliness could be ensured; but this was based he presumed upon the experience of metallic packing used in steam engines, and it must be borne in mind that the average pressure in a steam cylinder

was probably seldom above 40 or 50 lb. per sq. in.; whereas with water, where any of the great pressures were used, he did not believe metallic packing was of any use at all. From this consideration he had never used any metallic packing for hydraulic machines. He was glad to hear the information given about the hydraulic riveters at Messrs. Robey's, which had been at work there a considerable time; and the effects which had been mentioned of dirty water upon leather packing were confirmed by his own experience. In the hydraulic punching and shearing machine shown in the drawing, trials had been made of cupped-leathers, vulcanised india-rubber, and hemp packings; and he had come to the conclusion that hemp was the most suitable packing for hydraulic machines, except where gunmetal could be used for all the wearing surfaces, and then the question of expense came to be considered. The question was not simply one of greatest durability, but also of facility of renewal; in order to replace a leather packing it was necessary to take the machine to pieces sufficiently for getting the ram out, and then to slip the leather ring over the end of the ram and up into its place. But with hemp packing it was only requisite to take the gland off and put the hemp into the stuffing-box, which caused a great saving in time and expense. He had found the hemp or flax packing answered every purpose, and had consequently adopted it and was now using it in every case.

The packing in the accumulator at the works in Liverpool, where the experiment named in the paper had been tried, was of hemp, and the result arrived at as to the friction was almost identical with those obtained in Mr. Hick's experiments on the friction of cupped-leathers, which the experience of the working of hydraulic machinery had shown to be quite correct; and corresponding results had also been obtained from accumulators by Sir Wm. Armstrong. In the experiment at the works in Liverpool the ram of the accumulator was 7 in. diameter with 12 ft. length of stroke, and the velocity in ascending was just about the same as in descending, the feed pumps having rams 3 in. diameter and 12 in. stroke.

For the slide-valves and mitre-valves of hydraulic machinery he was now occasionally using the hard phosphor-bronze, and this was found very durable for the purpose, although a good mixture of gunmetal proved very satisfactory.

In reference to the relative advantage of using a moderate pressure with a large ram in hydraulic machines, or a high pressure with a small diameter, it must be borne in mind that the friction of the water was not perceptibly increased with the increase of pressure, and consequently there was no loss in using the higher pressure, which allowed of a more compact machine; and practical experience had shown that there was no trouble in keeping the pipe joints tight at pressures of 1500 or 2000 lb. per sq. in. At the same time he did not think there was any occasion for carrying such high pressures throughout the whole of a works, and a much lower pressure would be sufficient for working the foundry cranes and other cranes; in such cases there was certainly a limit to the extension of a high pressure. At Sir Wm. Armstrong's works at Elswick the hydraulic machinery was all arranged he believed for a pressure of 700 lb. per sq. in. throughout the works, with the exception of a riveting machine, which had been converted from a steam riveter, and was consequently worked with a lower pressure corresponding with that which had been used when steam was employed. But in some steam riveters that had latterly been converted by himself he had substituted a small hydraulic cylinder for working with a pressure of 1500 lb. per sq. in. Over and above the dead pressure of the accumulator however, he considered there was great value, for the working of riveting machines, in the impulse derived from the momentum of the falling weight, by making the accumulator ram in this case sufficiently small in diameter, so as to cause a considerable drop of from 18 in. to 24 in. for each rivet; the dead pressure of 40 tons on the rivet was thus raised to a closing pressure of as much as 60 tons, coming upon the rivet with the effect of a blow, after which the dead pressure of 40 tons still continued upon the rivet, and kept the plates pressed tight together until the rivet was cool; by this means three thicknesses of plate in boiler work were riveted perfectly steam-

tight at once, without any caulking. The adjustment of the pressure for lighter descriptions of work was readily effected by simply relieving the accumulator ram of a portion of its load, by stopping some of the upper rows of weight-segments by means of a suitable catch. With respect to the loss of power occasioned by employing the same high pressure through the whole of the stroke in a riveting machine, this was a question of expediency which superseded the question of pure economy; and he certainly did not consider it worth while, in the present case of the hydraulic riveter, to complicate the construction by any arrangement for compounding a high and a low pressure of water, although he had designed several arrangements which would meet the case.

The friction of the shafting in the experiment described in the paper had only been ascertained in relation to the power of the engine when running without doing work; but he would endeavour to ascertain the percentage it bore to the engine power exerted in ordinary full work, so as to add that information to the paper.* The machinery in a flax mill however, such as had been referred to in the discussion, was very different from that in a boiler yard or engineering works, and there was a considerable difference in the working of shafting in the two cases. He had heard of shafting several hundred feet long so well put up that it could be turned round by hand; but he had never met with anything like that in a boiler yard or machine works.

The utilisation of a moderate waterworks pressure in towns for driving hydraulic machinery, in conjunction with an intensifying accumulator, was a most important question. In Newcastle-on-Tyne the available town pressure on the quays was about 80 lb. per sq. in., and this was very extensively applied direct from the main to a variety of purposes; a printing engine in another part of the town had also been driven by the same means for many years past. The three-cylinder hydraulic engine described in the paper would be very applicable for all rotary work, and small engines of that kind would render the employment of the town pressure much

* This percentage has since been ascertained to be about 15 to 17 per cent. of the engine power exerted in ordinary full work.

more practicable than hitherto; he hoped the plan would soon come into extensive use.

In the remarks which had been made respecting the limits to the application of hydraulic power he fully concurred, believing water pressure to be in most cases unsuited for such operations as planing or slotting, although many of the objections urged would be diminished if the system were completely carried out; and he was glad that opinions as to its proper limits had been so clearly expressed. To advocate an indiscriminate use of hydraulic power for all purposes he considered a mistake; and while he was guided by the example of Sir Wm. Armstrong's practice to a great extent, he did not see any limit to adapting similar principles to other cognate applications with equal success.

The PRESIDENT, referring to the mention which had been made of the use of the hydraulic riveters at Messrs. Penn's works for riveting together three thicknesses of heavy plates in marine boilers, said he had no doubt every engineer would prefer to have heavy plates and boilers riveted by a power machine instead of by hand; indeed the present large marine boilers could not be riveted at all by hand labour. The use of powerful riveting machines with proper management prevented bad work in the manufacture of boilers; but of course in the hands of a careless workman they would not be so successful. When the plates were not properly closed before the riveting was done, a collar was formed on the rivet between the plates, and when once this was the case no subsequent caulking would tighten the joint; the very attempt to do so by caulking had the effect of weakening the joint, and might ultimately result in explosion, as illustrated in a recent instance of a terrible explosion which had caused the loss of seven lives. The first mechanical riveter that he remembered seeing was one which he met with more than thirty years ago at a boiler yard in the Faubourg St. Denis in Paris, and it contained what he considered an improvement of the highest value over some of the present riveting machines. It was a steam riveter, having two steam cylinders working bell-crank levers, one of which had a very short stroke and

carried an annular tool; this did the closing of the plates, holding them pressed together perfectly close, while the riveting die, working within the annular tool, was brought up by the second cylinder and formed the rivet. There was thus no possibility of making a collar between the plates; and it seemed to him some such precaution should always be taken. It was suggested by Mr. Siemens that the closing of the plates might be done without the second cylinder, by simply actuating the annular closing tool from the riveter itself by means of an elastic collar. It certainly seemed desirable that the closing pressure on the plates should come before, instead of after, the completion of the rivet. If this were done, it would get rid of caulking, which he had always regarded as a barbarous expedient, tending to separate the plates after the riveter had tried to bring them together. He should like to see all boiler work finished perfectly steam-tight by the riveting machine alone; the plates ought to be in close contact throughout, and not separated as might be caused by the act of caulking, which "upset" the edge of the plate, producing in many places a gap between the plates—a minute gap, it was true, but one sufficient to destroy the close contact requisite for conduction of heat.

In connection with the general question which had been raised as to the conditions affecting the transmission of power by different methods for working a variety of tools, he remembered how about forty years ago the late Mr. Hague, whose apprentice he had been and who had originated the transmission of power by the exhaustion of air, had persuaded the authorities at Woolwich Dockyard to apply, in lieu of shafting, oscillating cylinders to the principal lathes and tools, for driving them by exhaustion, a large exhausting pump being attached to the shop engine. That was however a most unwise application; and the fallacy being fortunately discovered in time, the machines though made were not put up.

The principle of the intensifying accumulator described in the paper was not new, having been practically employed for many years past in the ordinary manufacture of lead piping. A large hydraulic cylinder was used, carrying a ram of rather more than one-fifth the diameter, so that a pressure of 1 ton per sq. in. upon

the piston was intensified to 18 or 20 tons per sq. in. upon the ram; this ram pressing upon the lead caused it to issue through the die in the form of a pipe. Machines of that description made by Messrs. Easton and Amos had been at work for more than twenty-five years.

The early use of hydraulic power for a variety of mechanical operations at Messrs. Fox and Henderson's works, to which reference had been made, served to illustrate the fact that it was not enough to know the importance of any improvement, but it was necessary to force the conviction of its value into the minds of unwilling listeners. There was always a natural repugnance to change, where a large amount of capital was invested in existing machinery; and there was consequently little chance of any improvement being extensively adopted, unless some one made its advocacy his especial business. This was being done by the author of the present interesting paper, which was a continuation of that read by him at the Liverpool meeting; and in the two years which had since elapsed it must be admitted that most satisfactory improvements had been made. A most useful discussion had been elicited; and he proposed a vote of thanks to Mr. Tweddell for the paper, which was passed.

The following paper was then read:—

ON COMPRESSED-AIR MACHINERY FOR UNDERGROUND HAULAGE.

By Mr. WILLIAM DANIEL, of Leeds.

The attention of engineers has for some time been directed to the application of machinery for superseding animal labour in underground operations where good ventilation is an absolute necessity; and the increasing expenses incurred by the use of manual labour and animal power for mining and tunnelling have exerted a most powerful influence in developing the projects which have from time to time been brought forward, for the employment of mechanical power in a form that would entail no inconveniences with respect to ventilation. The application of machinery to assist in boring the Mont Cenis tunnel by Messrs. Sommeiller, Grandis, and Grattoni in 1857 was doubtless the first step of any importance in this direction; and since that time hauling and cutting coal, pumping water, and drilling rocks have been successfully accomplished by machines in situations where the employment of steam was altogether inadmissible.

The obvious inconveniences attending both the use of hydraulic power and the transmission of motion by wire ropes have led to the extensive adoption of Compressed Air for Underground operations; and although the percentage of useful effect is somewhat small, considerable economy has been found to result from the employment of compressed-air machinery where it has replaced men and horses. The unsuccessful results that have in some instances attended the trials made have in the writer's opinion been due to defects not so much in the system as in the machinery employed. Although in the application of the steam engine to compressing air so good an opportunity is afforded for economical working, yet this has hitherto received but little attention. The ordinary form of Air-Compressing

Engine is similar in arrangement to that shown in Figs. 1 and 2, Plate 62; but instead of high-pressure steam being used, cut off as early as 1-4th stroke, the compressed-air and steam pressures are usually about equal, and the steam is admitted to the cylinder for 3-4ths or 7-8ths of the stroke.

The objections which have been urged against the use of compressed air are mainly grounded on—first, the probable loss by leakage; second, the great expense of the compressing machinery and pipes, and the large receivers necessary for storing the compressed air; and third, the small percentage of useful effect obtained from the power expended. Practice has effectually disposed of the objection of loss by leakage, and has also proved that the cost of maintenance and working has justified the additional outlay required above that for performing the same work by other means. The small percentage of useful effect is perhaps the only serious objection that can be urged; but in dealing with this, the point for consideration is, whether the economy that has already been proved to result from the use of compressed air in underground operations can be secured to the same or a greater extent by methods less expensive in first cost or maintenance, or more convenient in application. Hydraulic or vacuum engines, and the use of wire ropes, have hitherto been the only competing plans; and, whatever the future may bring forth, the writer thinks that past experience has proved their inferiority for underground purposes. Perhaps in no part of this country has the use of compressed air in underground operations been more extensively resorted to than in the South Wales coalfield; and in the Powell Duffryn Collieries near Aberdare the proprietors are so convinced of the benefits to be derived from its use, that it is their intention to dispense with animal power altogether and substitute air engines for hauling underground.

In Figs. 1 and 2, Plate 62, is shown a pair of Air Compressors now being constructed with other machinery by Messrs. John Fowler and Co. under the direction of Sir George Elliot for the Powell Duffryn Collieries. These engines are coupled together

at right angles, and have 34 in. steam and 40 in. air cylinders, the stroke being 6 ft.; the steam at a pressure of 70 lb. per sq. in. is cut off at 1-4th stroke, and the air is compressed to 40 lb. per sq. in. above the atmosphere. The steam valves S and exhaust valves E are of the ordinary Cornish equilibrium type, 8 and 9 in. diameter respectively, as shown in the transverse sections, Figs. 3 and 4, Plate 63. The steam valves are each worked by a cam on a horizontal shaft A, Fig. 3, which is driven by mitre gearing from the flywheel shaft; and the exhaust valves are each worked by an eccentric on the same shaft, Fig. 4, and are set to close at 1-16th of the stroke from the end.

The inlet and outlet valves of the air-compressing cylinders C C are shown in Fig. 5, Plate 64, which is a longitudinal section through the air cylinder and covers; and Fig. 6, Plate 65, is an end view of one cover. The inlet valves B B, shown to a larger scale in Figs. 9 and 10, are of cast iron with leather flaps, and there are three of them in each cylinder cover. The two outlet valves D D, also in the cylinder cover, are shown in Figs. 7 and 8, and are of brass, with mitre faces $1\frac{1}{4}$ in. long inclined at an angle of 30° to the valve spindle. Valves made of vulcanised india-rubber, and brass valves with common short mitred and flat faces, have been tried; but none of them have been found to answer so well as those shown in the drawing.

These engines are to work at 20 rev. per min., or a piston speed of 240 ft. per min., and to indicate 482 H. P. The regulator valve is set to admit sufficient steam for driving them at the above speed against the air pressure of 40 lb. per sq. in., and they are then self-governing; for should the machines underground not take the air from the receiver as fast as delivered into it by the compressing engines, the pressure in the receiver and consequently the resistance increases, and the speed slackens. If the engines come to a stand and remain so for such a length of time that the steam left in the cylinders has not sufficient force to put them in motion again, they are started by admitting steam through a small pipe taken from the main steam pipe to each cylinder cover. The air cylinders C C, Figs. 1 and 2, Plate 62, have water jackets open

at the top, as shown in Fig. 5; and the air is forced into the receiver R, Figs. 1 and 2, which is 30 ft. length and 5 ft. diameter.

For Underground Haulage three sizes of engine are used. The Fixed Engine shown in Figs. 11 and 12, Plates 66 and 67, is for working the main roads; it has two horizontal cylinders 12 in. diameter and 12 in. stroke, driving two drums of 4 ft. diameter, which are geared with the crank-shaft in the ratio of 1 to 5, and run loose on the shaft, either drum being engaged by means of a clutch. For working branch roads a Single-Cylinder Engine of similar construction is used, working two drums arranged as in the two-cylinder engine; in Fig. 14, Plate 68, is shown a transverse section through the cylinder, which is 14 in. diameter and 12 in. stroke. The drums and clutches are shown in Fig. 13. These engines are constructed with wrought-iron frames, and are self-contained, and made as light and compact as is consistent with strength and accessibility. The handles for working the breaks, clutches, and starting and reversing gear, are placed close together in a position convenient for the engineman, as shown in the drawings.

Not only has the hauling on the main and branch roads to be accomplished by means of engine power, but it is intended to substitute machinery for the ponies and boys at present required to bring the coal from the working faces to the branch roads. For this purpose it is necessary to provide an engine that can be readily moved from place to place as the working faces advance, and one that will occupy very little room. Such a Portable Hauling Engine is shown in Figs. 15 and 16, Plates 69 and 70, the extreme external dimensions being $6\frac{1}{2}$ ft. length by 4 ft. breadth and height. It has a single cylinder 8 in. diameter and 9 in. stroke, geared with two loose drums of 2 ft. diameter in the ratio of 6 to 1; it is mounted on four wheels so as to travel on a road of the gauge in use, and is fixed in position by being wedged with two props to the roof.

There are twenty-six of these compressed-air hauling engines at the Powell Duffryn Collieries, some of which have been two years

in work; and some are also working at collieries near Sheffield. A simple method of arranging the exhaust orifice, as shown in Fig. 14, Plate 68, entirely prevents the trouble previously experienced from the formation of ice owing to the sudden expansion of the compressed air; the air is exhausted both above and below, as shown by the arrows, so that any ice which may form chips off and falls through.

In the application of compressed air to underground hauling engines it has to be borne in mind that the utmost simplicity is necessary; and owing to the frequent stoppages and reversals it is impossible to work with a high degree of expansion, without involving complication in construction and inconvenience in working. But where steam has to be conveyed down a wet shaft, the loss by condensation will place compressed air, supplied by machinery such as is now described, very nearly on an equality as regards the percentage of useful effect. It is therefore confidently submitted that, with a suitable description of compressing engine, compressed air may be advantageously substituted for steam in underground operations.

The losses attending the employment of compressed air are principally due to the abstraction of heat during and after compression, and to the partial extent to which expansion can be carried when utilising the compressed air at the working points. As fluctuations in speed produce variations in the amount of heat stored up in the metal of the compressing cylinder, and consequent variations in the temperature of the air before and after compression, these, together with the resistance of the passages and other obvious sources of loss, cause the calculated results to differ widely from those realised in practice. The percentage of useful effect obtained has indeed been stated at as low as only 20 per cent., and up to even the full amount of the power expended in compressing the air; but the writer considers it manifest that proper means had not in those cases been taken to secure accurate results. For instance, in some cases the air was compressed continuously and used intermittently, a great fluctuation of pressure being observed in

the receivers; and in others the useful effect was deduced from the weights of trains hauled up inclines, without proper allowances for friction of ropes and curve resistances. This want of reliable experimental data induced the writer to conduct a series of experiments on this subject, the results of which are as follows.

The machinery employed for the experiments consisted of a 16 in. double-cylinder steam engine with 30 in. stroke, having an air cylinder of the same diameter placed behind each steam cylinder and on the same piston-rod of $2\frac{1}{2}$ in. diameter, the general construction being similar to that shown in Figs. 1 and 2, Plate 62. This compressing engine was mounted on a receiver 5 ft. diameter and 24 ft. length, which formed the bedplate. The engine worked by the air was an ordinary semiportable engine having two 10 in. cylinders with 12 in. stroke, and a common slide-valve cutting off at 3-4ths stroke. The air from the receiver was taken into the multitubular boiler of this engine, which formed a second receiver, and was there cooled to the same extent that it would have been if taken through a long length of pipes, but perhaps with less friction; the temperature of the air in this second receiver was never more than 5° Fahr. above that of the atmosphere. This air engine worked a friction break, and indicator diagrams were taken from its cylinders while disconnected from the break, and while working the unloaded break, and also while running with the load on the break; and the power expended in compressing the air was ascertained by diagrams from the steam cylinders of the compressing engine.

This series of indicator diagrams is shown in the five Plates 71 to 75. The top diagrams in these Plates are from the steam cylinders of the compressing engine when working with five different pressures of air and steam; the second diagrams are taken simultaneously from the air cylinders; and the third diagrams are from the air engine while running with the load on the break. Fig. 32, Plate 75, is a friction diagram taken when the break was running unloaded; and Fig. 33 is a friction diagram of the engine only, when disconnected from the break. Three experiments were made at each pressure, and the mean result taken: these mean

results are given in the appended Table I, and in Plates 71 to 75 are shown the indicator diagrams taken in one of the three experiments at each pressure. The duration of each experiment was about 20 minutes, and no greater variation of air pressure than $\frac{1}{2}$ lb. per sq. in. occurred in the receiver during any one experiment. The air pressures for each set of experiments were respectively 40, 34, $28\frac{1}{2}$, 24, and 19 lb. per sq. in. above the atmosphere; 40 lb. being the maximum generally considered advisable in practice, it was not thought necessary to go beyond this. No observations were made of the temperature immediately after compression, as these data have already been accurately determined. From the detailed statement given in the appended Table I, it will be seen that, the power required to compress the air being ascertained by the steam-cylinder diagrams, the percentage of useful effect yielded by the air engine at the five different pressures of air was as follows:—

Air Pressure	40	lb.	gave	Useful	Effect	25·8	per cent.
,,	,,	34		,,	,,	27·1	,,
,,	,,	$28\frac{1}{2}$		,,	,,	28·5	,,
,,	,,	24		,,	,,	34·9	,,
,,	,,	19		,,	,,	45·8	,,

The useful effect is arrived at by adding to the power absorbed by the break the power required to work the unloaded break, the result being ascertained by taking indicator diagrams from the engine driving the loaded break, and deducting from those diagrams the power required to work the engine alone.

Owing to the lower temperature generated at lower pressures, these experiments show a larger percentage of useful effect as the air pressure diminishes. The useful effect would have been further increased at the higher pressures, had it been possible to abstract the heat so as to maintain a constant temperature during compression; but as the speed is too rapid for this to be done, the compression diagrams from the air-compressing cylinders approximate more or less to the "adiabatic" curve (the curve when no heat is abstracted); at the commencement of each stroke the diagrams rise somewhat above the curve due to the atmospheric temperature, in consequence of the heat communicated to the

entering air by the hot cylinder. The theoretical diagram, Fig. 34, Plate 76, shows the difference between the adiabatic curve when no heat is abstracted during compression of the air, and the hyperbolic curve of constant temperature. The appended Table II gives the difference of final volume and of mean pressure during compression of air for these two cases, calculated from the formulæ of Rankine* and Clausius; and also the corresponding actual results from the air-compression diagrams obtained during the experiments.

The useful effect obtained from the use of compressed air at 40 lb. pressure having been ascertained by these experiments to be 25 per cent. of the power developed in the steam cylinder when working with 28 lb. steam in the cylinder continued for nearly 7-8ths stroke, the percentage of useful effect will be materially increased

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* (See Rankine's "Steam Engine," pages 319-20). The adiabatic curve for the compression of air, Fig. 34, Plate 76, is constructed from the formula

$$\left(\frac{\text{initial volume}}{v}\right)^{0\cdot408} = \left(\frac{p}{\text{initial total pressure}}\right)^{0\cdot29}$$

where v and p represent any corresponding volume and pressure, the latter being the total pressure in atmospheres above a vacuum. Putting initial volume = 1, and initial total pressure = 1, this formula becomes

$$v = \left(\frac{1}{p}\right)^{0\cdot71}$$

from which the theoretical final volumes given at D in Table II are ascertained.

The area of the adiabatic diagram, or the mean total pressure in atmospheres, will consequently be ($T \times$ final volume) $+ \int p\,dv$, which is equal to $T^{0\cdot29} + \int \left(\frac{1}{v}\right)^{1\cdot408} dv$, T representing the final total pressure in atmospheres. By integration between the limits $v = 1$ and $v =$ final volume $= \left(\frac{1}{T}\right)^{0\cdot71}$, this expression becomes $T^{0\cdot29} + 2\cdot451\ (T^{0\cdot29} - 1)$, or $3\cdot451\ T^{0\cdot29} - 2\cdot451$. If now P be taken to represent the final pressure in lb. per sq. in. above atm., then the mean pressure in lb. per sq. in. above atm. will be $14\cdot7 \times \left\{3\cdot451\left(\frac{P+14\cdot7}{14\cdot7}\right)^{0\cdot29} - 2\cdot451\right\} - 14\cdot7$; or

$$\left.\begin{matrix}\text{Theoretical Mean Pressure} \\ \text{in lb. per sq. in. above atm.}\end{matrix}\right\} = 23\cdot267\ (P + 14\cdot7)^{0\cdot29} - 50\cdot73$$

from which formula the figures given at E in Table II are ascertained.

by the use of 70 lb. steam cut off at 1-4th stroke. The theoretical increase of efficiency for the same water evaporated in the two cases will be about $2\frac{1}{2}$ times (100,000 instead of 40,000 ft.-lbs.); but taking only two thirds of this difference as the increase practically attainable, the energy per lb. of water evaporated becomes doubled, and the percentage of useful effect increased from 25 to 50 per cent. on the fuel consumed in the respective cases.

In Table III is given the theoretical useful effect obtained from the compressed air at the five different pressures employed in the experiments, as compared with that which would be obtained from the direct employment of steam having the same initial pressures as the compressed air and cut off at 3-4ths stroke. The calculation is made on the assumption that in each case the air is compressed by the employment of 70 lb. steam cut off at 1-4th stroke in a non-condensing engine; the theoretical mean effective steam pressure is then 35·8 lb. per sq. in., and the weight of 1 cub. ft. of 70 lb. steam being taken at 0·183 lb., the theoretical useful effect per lb. of water evaporated is $\frac{35{\cdot}8 \times 144 \times 4}{0{\cdot}183} = 112{,}682$ ft.-lbs. in the steam cylinders of the compressing engine. The percentage of useful effect realised in the air-expanding engine is taken from the actual results of the experiments given in Table I: thus in the case of compressed air at 40 lb., it is seen from Table I that the percentage of useful effect actually obtained is 25·8; consequently the theoretical useful effect of the air at 40 lb. is $112{,}682 \times \frac{25{\cdot}8}{100} = 29{,}072$ ft.-lbs. per lb. of water evaporated; and for the four other pressures of air the corresponding results are similarly arrived at, as given at F in Table III. The theoretical useful effect that would be obtained from the direct employment of steam at the same initial pressures as the compressed air, and cut off at 3-4ths stroke, is given at G in Table III, being calculated from the following formula, in which N denotes the number of times the steam is expanded, that is, the ratio of the final volume to the volume at the point of cut-off; (in the experiments the cut-off was at 3-4ths stroke, and consequently $N = \frac{4}{3}$, and hyp. log $N = 0{\cdot}288$). The weight of the initial steam per cubic foot at the different pressures is given in the table;

and the initial pressure is expressed in lb. per sq. in. above atm. in the formula.

$$\left.\begin{matrix}\text{Useful Effect}\\ \text{of Steam}\end{matrix}\right\} = \frac{144 \times \left\{\frac{\text{initial pressure} + 14{\cdot}7}{N} \times (1 + \text{hyp. log } N) - 14{\cdot}7\right\} \times N}{\text{Weight of initial steam per cub. ft.}}$$

It is seen by the results given in Table III that the relative advantage from the use of compressed air is greater at the lower pressures.

Although the machinery that has been described is only employed for transporting materials, the applicability of compressed air for pumping and coal-cutting has been practically demonstrated; and without doubt relief from the uncertain cost of manual labour may be looked for in the further development of this mode of transmitting power, and its connection with other labour-saving appliances so much needed for driving headings, coal-getting &c. The inconvenience of the heat arising from underground steam engines and boilers is obviated by the use of compressed air; and where outbursts of gas occur, an explosion or loss of life might perhaps be prevented by promptly diluting the gas with the compressed air stored up in the receivers. The increase in working expenses is trifling when compared with the attendant advantages; for during temporary stoppages of the output, such as have recently occurred so frequently in collieries, the only loss with compressed-air machinery is the interest on capital expended, instead of the present cost of keeping horses and paying the wages of boys. Also the possibility of employing mechanical power in this form, when it could not be employed in any other form, leads the writer to look forward confidently to the extensive use of compressed air, and to anticipate great economy from its application.

TABLE I.

Details of Experiments upon Useful Effect yielded by Compressed Air at five different pressures.

(*Average Results of three experiments at each pressure.*)

Specimen Indicator Diagrams, Plates 71 to 75.	Pl. 71.	Pl. 72.	Pl. 73.	Pl. 74.	Pl. 75.
Pressure of Air in Receiver, lb. per sq. in. above atm.	**40·0**	**34·0**	**28·5**	**24·0**	**19·0**
Mean Effective Steam Pressure in Compressing engine, lb. per sq. in. ...	26·3	25·1	21·5	19·7	16·6
Piston Speed in Compressing engine, ft. per min.	190	155	140	110	60
Mean Effective Pressure in Air engine, lb. per sq. in.	35·6	29·8	24·7	21·0	17·0
Piston Speed in Air engine, ft. per min.	108	104	104	108	88
Circumferential Speed of Break Wheel, ft. per min.	936	901	901	936	763
Load on Break, lbs.	448	364	280	224	140
Ind. H. P. from Compressing engine steam cylinders ... ... (A)	59·4	46·2	35·8	25·8	11·8
Ind. H. P. from Air engine cylinders ...	18·3	14·7	12·2	10·8	7·1
H. P. by load on Break ... ... (B)	12·7	9·9	7·6	6·4	3·2
Ind. H. P. required to drive Unloaded Break ... ... (C)	2·6	2·6	2·6	2·6	2·2
Total H. P. yielded by Air engine (B + C)	15·3	12·5	10·2	9·0	5·4
Percentage of Useful Effect ... $\left(100 \times \frac{B+C}{A}\right)$	**25·8**	**27·1**	**28·5**	**34·9**	**45·8**

Air Compressing Engine.—Two Steam and two Air cylinders, each 16 in. diameter (196·1 sq. in. net area) and 2½ ft. stroke.

Air Expanding Engine.—Two cylinders, 10 in. diameter (78·5 sq. in. area) and 1 ft. stroke.

Friction Break.—Wheel 5 ft. 6⅛ in. diameter = 17·3 ft. circumference.

TABLE II.

Comparison of Actual and Theoretical Results in Compressing Air to five different pressures.

Specimen Indicator Diagrams, Plates 71 to 75.	Fig. 18.	Fig. 21.	Fig. 24.	Fig. 27.	Fig. 30.
Pressure of Air in Receiver, lb. per sq. in. above atm. ...	**40·0**	**34·0**	**28·5**	**24·0**	**19·0**
Total Pressure in Receiver, atmospheres	3·72	3·31	2·94	2·63	2·29
Actual Final Volume from indicator diagrams (initial volume = 1·000) ...	·380	·425	·470	·518	·575
Theoretical Final Volume when no heat is abstracted (adiabatic curve, Fig. 34, Plate 76) ... ... (D)	·393	·427	·465	·503	·555
Theoretical Final Volume when temperature is constant (hyperbolic curve, Fig. 34, Plate 76)	·269	·302	·340	·380	·437
Actual Mean Pressure from indicator diagrams, lb. per sq. in. above atm.	24·0	22·7	19·5	16·5	14·5
Theoretical Mean Pressure when no heat is abstracted (adiabatic curve, Fig. 34), lb. per sq. in. above atm.(E)	23·5	21·1	18·6	16·4	13·8
Theoretical Mean Pressure when temperature is constant (hyperbolic curve, Fig. 34), lb. per sq. in. above atm.	19·3	17·6	15·9	14·2	12·2

TABLE III.

Useful Effect of Compressed Air compared with Steam at five different pressures.

Pressure of Air in Receiver, lb. per sq. in. above atm. ...	**40·0**	**34·0**	**28·5**	**24·0**	**19·0**
Weight of 1 cub. ft. of Steam, in lbs.	0·123	0·110	0·099	0·090	0·079
Theoretical Useful Effect of Air per lb. of water evaporated, in ft.-lbs. ...(F)	29,072	30,537	32,114	39,326	51,608
Theoretical Useful Effect of Steam at same initial pressure as Air, in ft.-lbs. ... ...(G)	59,544	56,455	52,424	48,393	43,392
Percentage of Useful Effect from Air compared with Steam ... ... $\left(100 \times \frac{F}{G}\right)$	**48·8**	**54·1**	**61·3**	**81·3**	**118·9**

Mr. Daniel observed that the three sizes of hauling engine described in the paper were the three that were found most convenient for the work in the Powell Duffryn Collieries, for which they had been constructed; and other sizes were also made, to suit the requirements of other situations.

During the last few days he had had an opportunity of making some further experiments with the compressing engines at work at those collieries, for the purpose of checking the results given in the paper in regard to the percentage of useful effect arrived at. These experiments however had not proved very satisfactory, in consequence of the inlet and outlet valves of the compressing cylinders being in a very bad state; and they showed the necessity when using compressed air of frequently indicating the compressing cylinder, to ascertain whether the proper amount of work was being got out of it, and to see that the valves continued in proper working order. The indicator diagram taken from the compressing cylinder was shown in Fig. 35, Plate 76; and as the engine was arranged for compressing the air to 25 lb. per sq. in., the compression curve ought to have risen steadily to 25 lb. and then to have become a horizontal straight line through the remainder of the stroke, as shown by the dotted line in the diagram. Instead of this however, it was seen that the actual line made several jumps above the 25 lb. pressure, after that pressure had been reached, and the last jump at the end of the stroke rose as high as 42 lb. pressure, showing that the outlet valves were not properly constructed and that the springs closing them were too heavy. Similarly the inlet valves were also found to be out of order, because there was a vacuum of 3 lb. throughout the whole length of the return stroke, showing either that the valves were not large enough or that the springs upon them were too strong. On applying the compressed air from this engine to work a pump, and measuring the water lifted, and also calculating the mean pressure in the steam cylinder, it was found that the useful effect in that instance was about 26 per cent., which was considerably less than the result of 35 per cent. obtained in the experiments mentioned in the paper with 24 lb. per in. pressure. The engines at the colliery were 900 yards away from the compressor; but in the previous

experiments mentioned in the paper the engine driven by the air had been close to the compressor.

Mr. C. Cochrane enquired whether any trial had been made of cutting off the steam at 1-4th of the stroke, instead of at 7-8ths, so as to secure greater economy; and whether with the higher initial pressure consequent upon an earlier cut-off there had been any difficulty in working from the circumstance that the full resistance in compressing the air was not met with at the outset of the stroke.

Mr. Daniel said he had not made any other experiments than those named in the paper and the trials just made at the colliery; but he did not anticipate that if a heavy flywheel were used there would be any difficulty in working with an early cut-off, especially with a pair of engines coupled at right angles.

Mr. H. Robinson remarked that, as several of these compressed-air underground hauling engines were stated to have been at work now for two years past, it would be of great use to all interested in mining operations if the cost per ton per mile could be given of underground hauling by compressed air, including the repairs and the maintenance of plant, and all other expenses affecting the question, in order that it might be compared with steam power.

Mr. C. W. Siemens observed that in the preceding discussion the question of the transmission of power by hydraulic pressure had been considered, and certain losses attendant upon that plan had been pointed out, while on the other side the great advantages of hydraulic power in admitting of direct application to the work had been duly appreciated. Another equally important question was that now brought forwards—the transmission of power by an elastic medium. The application of air power must necessarily be quite different from that of water pressure, and might be resorted to with great advantage in cases where steam could not be used direct or where long steam pipes would be objectionable; and

among the numerous applications for which it was particularly suitable, the most prominent and useful was that of underground haulage, which formed the subject of the present paper. The advantages of air power for this purpose were self-evident: in a mine, surcharged as it was with heat, the use of steam would be attended with great inconvenience; whereas air, being rendered by expansion so much colder than the prevailing temperature of the mine, was the very medium required for such a situation.

The subject therefore resolved itself into the question whether the transmission of power by air was attended with such losses as would render its application of doubtful advantage. This was a question of considerable interest, and one which could happily be dealt with in a very definite manner. Having had occasion some time ago to look into this question, the conclusion he had then arrived at was that in the ordinary mode of transmitting power by compressing air, cooling that air, and then letting it expand again, the attainable limit of the useful effect was about 50 per cent. of the power exerted in the compression. In the least favourable of the practical results obtained in the experiments described in the paper the useful effect was only about 25 per cent. of the power, implying a loss of as much as 75 per cent. The machinery however which had been employed in this instance appeared to him to be very far from perfect. Some mechanical imperfections in one of the air-compressing engines had indeed been pointed out by the author of the paper, the indicator diagram showing that the air was neither able when compressed to get out of the cylinder freely, nor before compression to get into it freely: two great evils which could easily be remedied by a proper construction of the air valves.

But there was another defect, which was independent of mere mechanical construction. As there was no injection of cold water into the compressing cylinder, the compression curve developed in that cylinder was a dynamical curve, not following the simple hyperbolic line of Boyle and Marriotte, but rising in a more abrupt manner, owing to the accumulation of heat during the act of compression. It was well known that in compressing air the whole of the force exerted in the compression appeared in the form of heat, and this

heat expanded the compressed air; so that a much larger volume had to be expelled after compression had taken place, than would have been the case if the temperature had been kept the same as before compression. But the remedy for this loss was a very simple one, consisting merely in injecting cold water in the form of spray into the compressing cylinder, in sufficient quantity to keep the temperature practically uniform throughout the stroke. The saving of power thereby realised would be very considerable, because the air when compressed to four times its original pressure would be heated by 258° Fahr., and the consequent increase of volume would be about as 2 to 3, involving a loss of power of 33 per cent., which, if the precaution he had mentioned were taken, would be saved almost entirely. Again in expanding the compressed air, the difficulty of getting rid of the ice formed in the passages of the expanding cylinder might be altogether surmounted if water were injected into that cylinder at the ordinary temperature, or better still at the temperature of 80° or 90° commonly existing in the bottom of a coal mine. This water imparting its heat to the expanding air would prevent the formation of ice, and would produce precisely the same advantage as that obtained in the compressing cylinder by the injection of water; and these two savings together would very materially alter the result obtained in percentage of useful effect. The most perfect arrangement indeed, if it could be carried out, would be to take the very same water which had been injected into the compressing cylinder, and inject it again into the expanding cylinder, so that the heat taken from the air during its compression should be restored to it during its expansion. By that means, if the quantity of water injected were such as to keep the temperature practically uniform throughout the stroke, the whole of the loss at present arising from the heating and cooling of the air would be avoided, and there would be no loss of power beyond that due to the friction of the machinery and pipes. The injection of warm water into the expanding cylinder had not been made before, he thought; but with it air transmission might be accomplished without greater loss of theoretical effect than water transmission.

The PRESIDENT enquired whether much difficulty had been experienced from the formation of ice in the working of the compressed-air machines described in the paper.

Mr. DANIEL replied that in the early use of air there had been great difficulty from that cause, but it had now been overcome by the plan shown in Fig. 14, Plate 68, of making the exhaust orifice a through passage, so that the exhaust air escaped both above and below, and any particles of ice dropped off at once.

Mr. W. FIRTH said, with regard to the formation of ice in the exhaust passages of machines worked by compressed air, he had found great difficulty from that cause in the early use of coal-cutting machines, the ports having been made too small ; and it had been continually necessary to stop the working for half a minute at a time until the ice was melted. But by making the ports somewhat larger, this difficulty had now been almost entirely avoided, and there was now hardly ever any stoppage of the machine on that account.

In reference to the percentage of useful effect obtained in the employment of compressed air, he had found that with a pressure in the receiver of 40 to 45 lb. per sq. in. the useful effect at the receiver was about 40 to 45 per cent., according to the best calculations he had been able to make. From the receiver to the point of applying the air, much depended upon the arrangements for conveying the air ; and with large conducting pipes the friction was not materially felt. But his own experience had unfortunately been with very small pipes, 4 in. pipes down the pit shaft, and 2 in. pipes for 2 miles length in the workings of the mine, terminating in 50 yards of $\frac{3}{4}$ in. flexible tube ; the friction was of course very considerable, and the loss of power great. On enlarging the flexible tube to 2 in. diameter the result was that the machine was worked at the same speed with about 7 lb. per in. less pressure in the receiver, showing that the increase of friction in the $\frac{3}{4}$ in. tube as compared with the 2 in. tube was very material in the 50 yards length.

Mr. C. COCHRANE, referring to the loss arising from clearance at the ends of the stroke in air-compressing cylinders, mentioned that

in the United States he had seen a pair of double-acting air-compressing engines coupled together, with a short stroke of about 12 in., and having such a wash of water as to get rid of the clearance. The water was supplied from a chamber above the compressing cylinders, which formed the compressed-air reservoir and contained also some water; and the water was driven up into it at the end of the stroke so as to fill up the entire clearance space, by which means a perfect delivery of the whole of the air into the reservoir was obtained. Any excess of water supplied from the reservoir into each end of the cylinders was driven back into the reservoir above.

Mr. S. C. Homersham mentioned that he had used air-compressing engines for compressing to the moderate pressure of 12 or 13 lb. per sq. in., for the purpose of agitating or mixing lime and water in deep tanks to make saturated lime water: the idea of thus using air for agitating did not originate with himself, but he had seen it applied in a large manure tank at Mr. Mechi's farm, where the liquid and solid manure were mixed with water by blowing air through, instead of by a mechanical agitator. In constructing the blowing cylinder for compressing the air to 12 or 13 lb., he had admitted cold water from a main charged with water under pressure into the cylinder, as now proposed by Mr. Siemens, for the purpose of keeping the working parts cool; and the result had been a marked augmentation of the useful effect, owing partly to the cooling of the air, and partly to the filling up of the whole clearance space with water, whereby the loss due to clearance was entirely prevented.

Mr. Benjamin Walker said he had tried some time ago the plan of injecting water into an air-compressing cylinder in a compressing engine that he had made for working a coal-cutting machine; but in a larger compressing engine which he was now making he had intended to discontinue the water injection. There was a little inconvenience in its use, he considered; and he did not see that it could be productive of any advantage in saving of power by

filling up the clearance space, because the compressed air contained in the clearance space expanded behind the piston in the return stroke and gave back again the power that had been exerted in compressing it; the clearance in fact occasioned only a loss of capacity in the air-compressing cylinder, and not any loss of power. If the valves were properly constructed, there would be no loss through their delay in opening or closing.

The PRESIDENT enquired what was intended to be understood by properly constructed valves; and whether the working of an air-compressing engine in the mode now described had been tested by indicator diagrams.

Mr. BENJAMIN WALKER replied that he had not taken any indicator diagrams from the air-compressing engine. He had been impressed with the remarks made by Mr. Siemens, and should accordingly reconsider the employment of a water injection; at present he was inclined to think it would be preferable to waste a little of the coal and to get rid of the water. With regard to the air valves of the compressing cylinder, the best valves for the purpose he considered were piston valves combined with small relief valves opening inwards; the piston valves must of course be made with lap, or set to open rather late for the admission of air in the return stroke, in order to ensure the compressed air in the clearance space being expanded down to atmospheric pressure behind the piston before the inlet was opened; and the small relief valves were provided in order to prevent the possibility of a vacuum being formed before the inlet piston-valve opened.

In the machines worked by compressed air he had found no difficulty from ice, if the exhaust were made to open early and the ports were of large size, so as to allow a very free exhaust. At his own works sixteen pairs of compressed-air hauling engines were at present being made for the Portsmouth dockyard extension, for hauling large ships; and were intended to be employed there in addition to the hydraulic capstans and hydraulic engines already in use. The cylinders were all being made of brass, as a good deal of

trouble had been experienced with cast iron in consequence of its cutting the packing leathers; but with the brass the leathers would not be injured. A pair of vertical high-pressure engines for compressing air were being made by his firm, on the compound principle, which he considered was particularly applicable for the purpose of compressing air; for in the compressing cylinder the pressure was smallest at the beginning of the stroke and the greater portion of the work was done in the latter part of the stroke, whereas in the steam cylinder the pressure was greatest at the beginning of the stroke and least at the end; and when working compound there was less difference between the pressure in the steam cylinders at the beginning and at the end of the stroke than in the single-cylinder engine.

The percentage of useful effect obtained in the employment of compressed air at various pressures was a matter of very great interest, and he considered the results communicated in the paper were of much value. His own experience had also been to the same effect, that the higher pressures resulted in a lower percentage of work, and that it was thus possible to use pressures too high to be advantageous. Too much reliance he thought should not be placed upon results deduced from indicator diagrams alone; for though the indicator was a most valuable aid to mechanical engineers, he had found the actual work done did not always agree exactly with the indicated power shown by a diagram. In one instance where two engines happened to be performing exactly the same amount of work but with different lengths of stroke, the indicator diagrams did not show the same expenditure of power, but the engine with the longer stroke appeared to be exerting less power than the other. The only way in which he considered the correct result could be arrived at was either by a friction break or by pumping, so as to measure the real work performed.

Mr. H. Chapman mentioned that at the Blanzy Colliery, near St. Etienne in France, the proprietor, M. Chagot, had applied one of Brotherhood's three-cylinder engines worked by compressed air at a pressure of 45 lb. per sq. in. for driving a drill for coal cutting. But this was a low pressure in comparison with that of 450 lb.

used by Mr. Brotherhood in a compressed-air engine for working a torpedo. He should be glad to know whether any trouble had been experienced from ice in the expansion of the air from such a high pressure.

The PRESIDENT enquired the particulars of the application of the very high pressure which had been mentioned; 70 lb. per sq. in. used to be considered a maximum pressure in the employment of compressed air.

Mr. P. BROTHERHOOD said the high pressure of 450 lb. per sq. in. was employed for working a small engine that he had made for propelling a Whitehead fish-torpedo constructed at Woolwich, the speed of which was intended to be 8 or 9 knots per hour. It was one of the three-cylinder engines previously described, with $1\frac{1}{8}$ in. cylinders and $1\frac{1}{2}$ in. stroke, and when running empty had been indicated by a friction break up to as much as 2500 revolutions per minute, or a piston speed of 625 ft. per min.; at that speed the power shown by the break was about $2\frac{1}{2}$ H. P., which it was calculated would have propelled the vessel at about 9 knots per hour. The weight of the engine was only 7 lb., and the power developed was thus $\frac{1}{3}$ H. P. per lb. of its weight. The air for working the engine was compressed to 900 lb. per sq. in., and stored in a receiver made of Whitworth compressed steel without any joint; it passed to the engine through a reducing valve, which lowered the pressure to 450 lb. No difficulty whatever had been experienced from ice, either at the reducing valve or in the exhaust passages of the engine; he had not found any ice formed at either place. For ordinary use at moderate pressures, such as were employed in rock-drilling and coal-cutting machinery, he was making air compressors consisting of one of the three-cylinder engines, with 9 in. cylinders and 8 in. stroke, which was driven at a piston speed of 300 ft. per min. by another of the three-cylinder engines of the same size working upon the same crank shaft; the two engines were mounted upon opposite sides of the air receiver, which formed the bed-plate, and the crank shaft passing through it was fitted with a heavy flywheel inside.

Mr. T. Wrightson enquired what was the object of compressing the air up to 900 lb. per sq. in. in the receiver, and then reducing it to 450 lb. for working the engine.

Mr. P. Brotherhood replied that the object was simply to store up a large amount of power in a small space, regardless of cost. Having been unable on account of the high speed to indicate the engine except by the break, he did not know how much below 450 lb. the actual pressure in the cylinders might be at that speed; and this application of power was necessarily a very costly one.

The President remarked that it was of course impossible to take indicator diagrams from an engine running at such a high speed; at 600 revolutions per minute he had succeeded in taking a diagram from an engine, but at higher speeds he had been obliged to have recourse to the friction break, as in the case now described. As to the cost of the power, this was a matter of secondary consideration in military operations of the class for which a torpedo was constructed.

Mr. E. A. Cowper, referring to the extensive oscillations shown in the indicator diagram taken from the air-compressing cylinder of the engine described in the paper, considered these were caused simply by the jumping of the indicator piston itself, and did not denote corresponding alternations of pressure in the air cylinder, except perhaps in the case of the last jump, which might be due to the throttling of the air by the outlet valves at the end of the stroke. That diagram therefore he thought should not be relied upon too much. The vacuum of 3 lb. in the return stroke showed there was something wrong with the inlet valves, which did not give sufficient area of opening.

A more economical result in the application of compressed air he considered ought to be obtained, whether in underground machinery or elsewhere, by means of economy in the engine; the 70 lb. steam should be really cut off at 1-4th of the stroke as appeared from the paper to have been originally intended, instead of so late as 7-8ths as was shown by the diagrams to be actually the case; and the air

should also be worked expansively in the engine which used it. Although it might be quite admissible with the little air engines used in torpedoes to neglect economy and expansion altogether, when using air at so high an initial pressure as 450 lb. per sq. in., and running a small screw propeller at a very high speed, there could be no good reason for not making a large air engine work expansively and economically, as far as he could see.

For getting rid of ice formed in machines worked by compressed air, the use of large valves and large passages was a simple and efficient plan. The cooling effect was in the expanding air, and any moisture in it would be turned into ice; consequently if the exhaust air were allowed a very free discharge, so that it could come out with a sudden blast, it would take with it any ice that might be formed. A very simple mode of warming the cylinder of an underground air engine, sufficiently to prevent any formation of ice, would be to cast it with a series of radiating wings or fins on the outside, on the principle of the "gill" stove; these would effectually take up the warmth from the atmosphere in the mine, and keep up the temperature of the cylinder sufficiently.

The plan of air compressor acting upon what might be called the "see-saw" principle had been much used. A horizontal pump was employed, having a solid piston with double cupped-leathers working in a cylinder filled with water, from each end of which rose a vertical chamber with the inlet and outlet valves on the top. The motion of the piston caused the water to rise and fall alternately in the end chambers, and every particle of the air compressed in them at each stroke was expelled through the delivery valves, without any clearance space being left. There was a constant small supply of water to replenish the cylinder, which was thus always kept cool.

A pair of air-compressing cylinders that he had put up, $22\frac{1}{2}$ in. diameter and 4 ft. 4 in. stroke, had vertical conical valves, with very small seats and kept to their seats by springs very nicely adjusted; they moved so freely under a very slight force that they required a little friction putting on them, to act as a slight drag and prevent them from dancing. They were opened by the air itself lifting them up to a stop.

With regard to the power and resistance in an air-compressing engine, it was clear that, where the air cylinder was worked direct from the steam cylinder, the expansion of the steam took place just when the air was being compressed, so that the indicator figures from the two cylinders were reversed relatively to each other, and at the commencement of the stroke the full power was being exerted with no resistance against it, while at the end of the stroke there was the full resistance against the least power. There was however one way of getting over this awkward result, by shifting the crank of one cylinder round through such an angle to that of the other as should cause the two pistons to move no longer together but at different times, so that as far as possible the greater power should be developed when the greatest resistance was experienced ; it was astonishing what an enormous difference in plus and minus pressure this made, and attention to this fact would make the engine work much more smoothly with a smaller flywheel ; and in such a large engine as that of 480 Ind. H. P. described in the paper he considered it was an important point to be attended to.

Mr. E. Bainbridge mentioned that some experiments he had made a few years ago with air-compressing machinery showed only from 10 to 15 per cent. of useful effect, which was considerably below the results given in the paper. Previously to that, the theoretical limit of 50 per cent. assigned by Dr. Siemens had been corroborated by Dr. Herschel of Newcastle as the theoretical maximum of useful effect. As to the means by which this result could be reached in practice, it had been found that the higher the pressure of steam employed and the lower the pressure of air, the greater was the advantage obtained ; and he believed if the air engines were worked with 12 lb. per in. pressure of air, supplied by 100 lb. pressure of steam in the compressing engine, at least 45 per cent. of useful effect could be got. The plan of setting the cranks of the steam cylinder and compressing cylinder at an angle to each other, so as to make the indicator figures correspond in the manner suggested, had already been carried out, and a large number of air-compressing engines were working in that way. In the twenty-six

underground hauling engines employed at the Powell Duffryn Collieries, he supposed, from the results given in the paper, that probably not more than 25 per cent. altogether was being utilised out of the 480 H. P. developed in the steam cylinders of the air-compressing engine. It was therefore clear that the chief disadvantages attending the use of compressed-air machinery underground were the heavy first cost of the engines for compressing the air and the great extra consumption of fuel consequent upon the low percentage of useful effect. In the working of a large colliery however he had found that a loss of even as much as 80 per cent. was quite counterbalanced by the great additional convenience attending the application of compressed air for working underground machinery; and at the Blackwell Colliery in Nottinghamshire, where three seams of coal were being worked, an air-compressing engine was now being put down for working three coal-cutting machines and hauling engines, one in each seam; the coal cutting was intended to be done during the night and the hauling during the day, so that the air compressor would be kept constantly at work. One great disadvantage attending the use of steam underground, which had perhaps hardly been dwelt upon sufficiently, was the serious inconvenience which the discharge of exhaust steam underground would cause in the workings of a mine, and this would be especially felt with so large a number of underground engines as at the Powell Duffryn Collieries. It was indeed practically impossible to work a number of steam engines underground on account of the exhaust steam; and it was consequently necessary to use compressed air, which could be discharged from the machines into the workings at any time without inconvenience.

Mr. T. R. Crampton remarked that in the construction of the delivery valves of air compressors it was important to take care that there should be as little difference of area as possible between the upper and the under side. If this were not attended to, the valves would open with a jerk which would fully account for the jump shown in the indicator diagram exhibited. But by equalising the top and bottom areas as nearly as possible, the action of the valves would be

made more like that of a slide-valve ; they would open promptly and without jerk as soon as the proper pressure was reached, and would remain open to the end of the stroke.

The plan of filling with water the clearance spaces in an air-compressing cylinder was one that he had known and used for the last twenty years, and he had found it decidedly advantageous ; at his suggestion it had also been introduced by the late Mr. Humphrys in the air-pumps of marine engines, but it was not an original idea of his own.

Mr. Daniel, replying to the enquiry about the actual cost of underground hauling by compressed air, regretted that the engineer of the Powell Duffryn Collieries was not able to be present and to give particulars of the cost. But the best proof that the plan was found satisfactory was that the number of compressed-air hauling engines in use at those collieries had been continually increasing since their first adoption.

The indicator diagram shown in Fig. 35 in illustration of the oscillation of pressure in an air-compressing cylinder was not one that had been obtained in the experiments described in the paper ; but it had been taken in the trial he had made a few days ago of the compressing engines at the colliery, for ascertaining the condition of the air valves. The jumping shown in the compression curve he did not think was due to the piston of the indicator, because the same indicator had a few minutes afterwards been used on the steam cylinder of the engine, in which the pressure and the speed of piston were the same as in the air cylinder, and no jump had then been produced. It was simply due he considered to the defective state of the valves. With regard to the vacuum line in the diagram, which denoted that the inlet valves did not open sufficiently, he had seen diagrams taken from compressors that were fitted with piston-valves such as had been referred to, and they invariably showed a similar vacuum line.

The plan of arranging the steam and air cylinders with cranks at an angle to each other was virtually carried out in the compressing engines described in the paper, because these were a pair of engines

coupled together at right angles, and the steam cylinder of either engine might therefore be regarded as driving the air cylinder of the other at right angles; just as if there were two separate single-cylinder engines, each working an air-compressing cylinder through right-angled cranks.

In reference to the injection of water into air-compressing cylinders he had not had any experience himself; but the general opinion of the users of compressed-air machines seemed to be that, when water was injected, the air became so saturated with vapour as to cause a great increase in the quantity of ice formed at the air-expanding engine, which was very objectionable in underground machines.

The PRESIDENT remarked that the subject of the present paper was a most interesting one, and naturally suggested a consideration of the relative loss from friction in transmitting power by the medium of water or by that of air. It was frequently urged that there must be less loss in the transmission of power by air than by water, on account of the diminished friction of air; but although it was true as an abstract fact that there was less friction in the passage of air through pipes than arose from the flow of water through them, yet in any practical application, taking into account the difference in the pressures that would be employed in the two cases, this was not true. For with air, it had been suggested in connection with the paper just read that the maximum useful pressure was about 40 lb. per in. With water, 700 lb. used to be the standard working pressure advocated by Sir. Wm. Armstrong; but in more recent practice this had now been doubled. Taking however air at 40 lb. pressure and water at 700 lb., it was clear that in order to get an equal power out of an engine it would be necessary to use $17\frac{1}{2}$ times as great a bulk of air as of water, and the velocity of the air through the pipes would have to be $17\frac{1}{2}$ times that of the water through the same pipes. Hence, provided the density of the air and water were the same, the skin friction, being as the square of the velocity, would be 306 times that with water; and, as there was also $17\frac{1}{2}$ times greater bulk to deliver, the power

required to overcome the friction would be as the cube of the velocity, or 5359 times the power required with water. But the friction varied directly as the density; and air at 40 lb. pressure above the atmosphere being about 220 times as light as water, the foregoing figures had to be divided by 220, which gave as the practical result 1·4 times greater friction, and 24 times greater loss of power, with air than with water. This was the result with pipes of the same size; but it was evident that by increasing the diameter of the pipes used for air transmission, and thereby reducing the velocity, the relative loss of power from friction would be reduced to a very large extent. It was thus seen that in practice there was far more loss of power in transmission of power by air than by water. This conclusion however did not by any means imply that air was an improper medium to be used in a coal pit; on the contrary, there were so many cogent reasons in favour of its employment—such as the aid it afforded in diluting the choke-damp after an explosion, and the general facility attendant upon its working,—that the question of economy became one of minor importance in this particular application.

He had heard doubts thrown on the accuracy of observers who had stated that there was more pressure in a compressed-air main at the bottom of a pit than there was close to the compressing pump on the surface; but this might very readily be, and in fact when there was not any delivery of air from the main must be, for the following reason. Suppose the pit were 620 yards deep, the barometer would show 1 lb. per sq. in. greater pressure of the atmosphere at the bottom than at the top, arising from the extra weight of this height of column of ordinary atmospheric air; consequently, with compressed air at 40 lb. per sq. in. above the atmosphere, or $3\frac{2}{3}$ times the density of atmospheric air, the pressure in the air pipes from the mere weight of the air would be $3\frac{2}{3}$ lb. per sq. in. greater at the bottom than at the top. Hence 620 yards depth would give an effective increase of $2\frac{2}{3}$ lb. per sq. in.; and there was thus no impossibility in getting a greater working pressure at the bottom of a pit than at the top.

With regard to the injection of water into the air-compressing cylinders, this plan had been applied by Hague thirty-five years ago in the transmission of power by exhaustion. In that case the rarefied air drawn into the exhausting cylinders, instead of being as much colder than the atmosphere as was due to its rarefaction, had already assumed the atmospheric temperature in its passage along the exhaust main, and was proportionately dilated. On compressing this dilated air to atmospheric density to cause it to escape at the outlet valves, heat was developed, and thus the bulk being augmented the labour thrown on the engine working the vacuum pump became increased. By the injection of cold water this surplus heat was absorbed and the volume of air was reduced; and though no indicator diagram was taken, the gain in power was at once evident in the increased speed of the engine working the exhaust pump, which then made 28 strokes per minute, in comparison with 24 previously to the application of the injection.

Reference had been made to the use of a water piston, which got rid of all clearance; and in some air-compressing machinery put up by Messrs. Easton and Amos at the sewage farm at Windsor they had employed a little injection of water to fill the clearance space in the compressing cylinders. The earliest instance that he knew of the application of this plan was when portable oil gas compressed in cylinders was supplied in London about forty-five years ago; the compressing pumps were fitted with solid plungers, and the clearance spaces were filled up with mercury, so that in each stroke the last particle of gas was expelled under pressure.

A most valuable suggestion had been made by Mr. Siemens as to the feasibility of restoring to the air expanding in the working cylinder the heat given out from it in the compressing pump, by the injection of water into the expanding cylinder. At the bottom of a coal pit there was always the requisite head of water, and no difficulty would therefore be experienced in getting an injection of water at such a pressure as to enter the working air cylinder; and the specific heat of water being more than four times that of air, the cooling of the air in expanding could be restricted within any limits desired. This useful suggestion was thus a thoroughly practical

one for underground machines, and would be productive of great benefit in reducing the large loss of power otherwise taking place. The theoretical useful effect was not meant to be limited by Mr. Siemens to a maximum of 50 per cent. of the power, if all these points were carefully attended to, and if the air were worked expansively in the underground machines, as certainly ought to be done: though this had been pronounced a refinement in one instance in which he had suggested the plan. If indeed the unnecessary heat developed from the air in the compressing cylinder were got rid of by injection water, and were then utilised without loss, or were restored to the expanding air in the working cylinder, there would then only remain the loss from friction in the machines themselves and in the air mains; and the friction in the latter might be very considerably reduced by increasing the size of the pipes to an extent which need not render them either too heavy or too costly.

He proposed a vote of thanks to Mr. Daniel, which was passed, for his paper, and for the excellent set of diagrams illustrating it.

The following votes of thanks were then moved by the President and passed:—

To the Mayor of Cardiff, for so kindly granting the free use of the Town Hall Assembly Room for the Meeting of the Institution.

To the Local Committee, and the Honorary Local Secretary, Mr. S. S. Howard, for the excellent arrangements they had made for the Meeting.

To the Proprietors of the several Ironworks, Collieries, and other Works visited in the Excursions, for their kindness in opening their Works to the Members, and for the hospitable reception offered.

To the Railway Companies, for the special facilities and privileges granted for the Excursions.

The Meeting then terminated.

In the afternoon the Members were entertained at luncheon in Cardiff by the Rhondda Valley Colliery Owners; and an Excursion was made by special train to visit some of the principal Collieries in the Rhondda and Aberdare Valleys.

On the way to the Rhondda Valley, the celebrated Pontypridd Bridge was seen, the train slackening speed in passing it. This singular bridge, from which the place derives its name (Pont-y-ty-pridd, "bridge of the earthen house"), was the work of a self-taught mason and architect, William Edwards, who became one of the most famous bridge builders of the last century. He failed twice in his attempt at Pontypridd; first in 1746, when at the age of only twenty-seven he built a bridge of three arches which was swept away by a flood; and secondly in 1751, when he constructed a single-arch bridge with too thin a crown and overloaded at the haunches. His third attempt in 1755 succeeded perfectly; by introducing three circular openings in each of the haunches, the weight was reduced, and the keystones relieved. The span of the bridge is 140 ft., its arch forming the segment of a circle of $87\frac{1}{2}$ ft. radius; the height of the crown from the water is 34 ft., and the width of the roadway 11 ft. From the form of the bridge, the rise of the roadway on each side towards the centre is very steep, and this, together with the narrowness of the bridge, has rendered it inconvenient for the accommodation of the present traffic; another bridge at a lower level and with a flatter and wider roadway has accordingly been built close to it; but the old bridge still remains in a sound condition.

The Glamorgan Coal Co.'s Llwynypia Colliery in the Rhondda Valley was then visited, where the Members were received by the Managing Director, Mr. Archibald Hood. The steam-coal pit is 380 yards deep, and the winding is done by a pair of horizontal engines with 34 in. cylinders and 6 ft. stroke, coupled at right angles, and working direct upon the shaft of the conical winding

drum, which tapers from 25 to 15 ft. diameter. The time of each lift varies from 45 to 47 sec., giving a mean speed of about 17 miles per hour in the shaft; the total time between the cages alternately coming to bank in regular working averages $1\frac{1}{4}$ min., including the time occupied in changing the trams. The cages have two decks, each holding one tram; and the trams contain each from 20 to 22 cwt. of coal. There is another winding pit 111 yards deep for bituminous coal; and a third pit 370 yards deep fitted with a Guibal ventilating fan of 30 ft. diameter and 10 ft. width, which at 50 rev. per min. exhausts 95,000 cub. ft. of air per min. An extensive range of coke ovens is employed in making coke from small coal; the coal is ground under edge-runners, and sifted, and is so clean as not to require washing before coking.

Messrs. Nixon's Navigation Colliery in the Aberdare Valley was then visited, the Members being received by the Manager, Mr. George Brown. A pair of oscillating engines are employed for winding from one of the pits of 365 yards depth, having cylinders 33 in. diameter and 6 ft. stroke, and reversed by a donkey engine; and at another pit of 286 yards depth a pair of side-lever marine engines, with cylinders 33 in. diameter and 5 ft. stroke, are adapted as winding engines. Both pairs of engines have conical winding drums tapering from 22 ft. extreme diameter to 10 ft. diameter at each side; they wind at a mean speed of about 17 miles per hour in the shaft, raising each time about 40 cwt. of coal.

At Aberaman Colliery the Members were received by Mr. J. C. Parkinson, one of the Directors of the Powell Duffryn Steam Coal Co., and the Manager, Mr. George Wilkinson. The ventilation of the colliery is effected by a Waddle fan of 40 ft. diameter and 1 ft. 5 in. width at the circumference, driven at 40 rev. per min. by a horizontal non-condensing engine with 32 in. cylinder and 4 ft. stroke; at that speed the fan exhausts 89,000 cub. ft. of air per min., producing a vacuum of 1·35 in. of

water. At 45 rev. per min. the fan is calculated to discharge 100,000 cub. ft. per min., and at 50 rev. 120,000 cub. ft. The air-compressing engine at Middle Duffryn Colliery, described in the paper read at the meeting, was seen at work, supplying compressed air to the underground hauling machines. The Members were invited to luncheon at Aberaman House by Sir George Elliot, Bart., M.P.; and returned to Cardiff in the evening.

On Thursday, 6th August, an Excursion was made by the Members by special train from Cardiff to Merthyr Vale Colliery, the Merthyr Sewage Farm, and the Cyfarthfa and Dowlais Iron Works.

At Messrs. Nixon's Merthyr Vale Colliery, where the Members were received by the Manager, Mr. George Brown, two shafts of 16 ft. diameter are in progress of sinking, and have at present reached a depth of 380 yards, being lined with cast-iron tubbing through 212 yards depth; the total ultimate depth is expected to be about 490 yards. During the sinking the water is being raised from the shafts in large tubs. The pit-head gear is being constructed entirely of iron, the pulley frames being made of flange rails riveted together in sets of four, around hoops of 2 ft. diameter. The conical winding drum is 24 ft. extreme diameter, tapering to 10 ft. diameter on each side. The winding engines are a pair of marine engines with return connecting-rods, having 83 in. cylinders with 4 ft. stroke, and are to raise each time 80 cwt. of coal, and to be reversed by a donkey engine; they are coupled direct to the shaft of the winding drum, and with it are mounted on the top of a foundation 30 ft. high, consisting of a mass of concrete enclosed within thick masonry walls. Adjoining the colliery are some substantial cottages erected of concrete, for the use of the workmen.

At the Merthyr Sewage Farm the Members were received by the Chairman of the Merthyr Board of Health, Mr. William Jones, and the Surveyor to the Board, Mr. Samuel Harpur, by whom they were conducted over the works. The sewage of Merthyr is conveyed from the town to the farm at Troedyrhiew, a distance of four miles, in a brick culvert, 24 in. by 18 in. The sewage is strained before it is allowed to flow on the land, by means of two straining tanks, one working while the other is being cleaned. Each tank is 200 ft. long, 5 ft. wide, and 5 ft. deep, the bottom paved with stone, and the top covered with planking; and the interior is filled with broken furnace-cinder, coarse at the bottom, but small and fine at top. The tanks are changed for cleaning every four or five days; and the solid material extracted is carted on the land.

There are four "downward filtration" areas, of about five acres each, which are drained from 6 to 7 ft. deep; the sewage is allowed to flow on one area at a time for six hours, and is then passed on to the next; so that each area works six hours and rests eighteen out of the twenty-four, Mr. Bailey Denton's arrangement being that each area of five acres should contain about 48,400 cubic yards of earth, and that every cubic yard should have a maximum quantity of $7\frac{1}{2}$ gallons of sewage per day to cleanse. These downward intermittent filtration areas were first used in February 1871, and cover altogether 20 acres; there are also 56 acres laid out for "wide irrigation," making 76 acres total on the farm at Troedyrhiew. Five miles further down the same valley, near Navigation, about 160 acres in addition are laid out for wide irrigation, to which the sewage is conveyed from Troedyrhiew in a brick culvert, 24 in. diameter, and in some places wooden pipes are used; there are thus altogether nearly 220 acres of irrigated land, besides the 20 acres of filtration ground.

As regards the condition of the effluent water from these downward filtration areas, it is stated by the Rivers Pollution Commission that "the result is highly satisfactory, more so even than that which had been obtained in the laboratory of the Rivers Commission. Indeed on the 10th June 1871 the water entering the Taff from the Merthyr intermittent filters was considerably

purer than the Thames water which we are often compelled to drink in London." At that time the whole of the sewage from a population of 25,000 was cleansed upon these 20 acres of filtration ground; and the cost of underdraining and laying out the ground was in this instance about £220 per acre. The commercial results have been that 40 tons per acre of Italian rye grass have been cut, and cabbage has been sold from the farm as high as £43 per acre.

Where land is dear and difficult to be obtained, downward filtration answers well as a means of disposing of sewage on a small area; but where sufficient land can be obtained at a fair agricultural value, and situated so that the sewage will flow over it by gravitation, needing no expensive main carriers, wide irrigation is more profitable, as utilising the sewage to a far greater extent than can be done by the downward filtration process; for experience has shown that on irrigated land as heavy crops can be raised as on an equal area of filtration land with five times the quantity of sewage. The area required for irrigation is found to be about one acre per hundred of the population producing the sewage. The present sewage of Merthyr is produced by a population of about 40,000, and exceeds one million gallons per day, of which one twelfth is sent to the filtration areas, and the remainder to the irrigated lands. With the exception of the 20 acres of filtration areas, the whole of the works have been designed and laid out by Mr. Harpur.

At the Castle Pit, Troedyrhiew, the Members were received by Mr. William T. Crawshay, and the large pumping and winding engines were seen at work. The pumping engine is of very massive construction, having a cylinder 68 in. diameter and 8 ft. stroke, placed inverted over the pit, with the piston-rod coupled direct to the pump plunger-pole, and also to one end of a beam, the other end of which is connected by a massive cast-iron connecting-rod to a crank on the flywheel shaft above; the crank is $6\frac{2}{3}$ ft. radius, and the flywheel, shaft, and crank weigh together 60 tons. The engine was making 4 rev. per min., and raising water from a depth of 265 yards in three lifts, the pump plunger being 15 in.

diameter; the speed can be increased to 12 rev. per min. if necessary. The pair of vertical winding engines have overhead cylinders 36 in. diameter and $4\frac{1}{2}$ ft. stroke, and wind from a depth of 263 yards in 37 seconds, giving a mean speed of 14 miles per hour. The winding drums are cylindrical, 12 ft. diameter, with flanges 16 ft. diameter.

At the Cyfarthfa Iron Works, over which the Members were conducted by Mr. William T. Crawshay, the first blast furnace was built in 1770, and there are now seven furnaces of 52 ft. height and $14\frac{1}{2}$ to 16 ft. diameter at the boshes. Five of them are blown with cold blast and two with hot, and all except one have closed tops fitted with bell and hopper, the gases being employed to heat the boilers. These furnaces being built in a row against the hill side, the coal and ore are brought direct by rail to the level of the furnace tops, where the coke ovens and calcining kilns are situated in convenient proximity for charging the furnaces. The extensive ranges of coke ovens are discharged by steam power, the charge being pushed out at the front by means of a ram at the back, which is forced through the oven by a small travelling steam engine running between two rows of ovens. The puddling mills are driven by two water wheels and two non-condensing engines, and the bar mills by two condensing beam engines and an oscillating non-condensing engine. There is also a non-condensing beam pumping engine with cylinder 30 in. diameter and 8 ft. stroke, which is used in times of short water to return the water from the river to the top of the water wheels; it works two single-acting lift pumps of 72 in. diameter and 4 ft. stroke, connected on opposite sides of the beam, the usual rate being 8 rev. per min., and the height of lift about 30 ft.

Proceeding by the special train viâ Vaynor Valley and Pontsticill to the Dowlais Iron Works, the Members were there received by Mr. George T. Clark and Mr. Menelaus, and were first shown the new Ivor blast furnace recently started, of 55 ft. height and 18 ft. diameter at the boshes, which is

intended to run 300 tons of Bessemer pig per week. It has a closed top, and is supplied with hot blast at a temperature of about 1200° Fahr. by four regenerative firebrick stoves of 29 ft. height and 22½ ft. diameter, heated by the waste gas from the furnace. The materials are raised to the furnace top by a water-balance hoist. In the steel works are four regenerative gas furnaces for the Siemens-Martin process, in which steel-scrap and crop ends of steel rails are used up; a bath is first made by melting about 30 cwt. of pig iron, into which the steel scrap is gradually fed; and finally spiegel is added to bring the metal to the desired quality. The charge of steel ultimately obtained is about 6 tons, and the time occupied in working it about 10 hours. The four steel furnaces are arranged along the straight side of a D shaped pit containing a ladle-crane large enough to receive the entire charge from one furnace; the ingots are cast in moulds in the same way as in the Bessemer process. Adjoining these furnaces are six of the ordinary Bessemer converters, blown by a pair of vertical blowing engines. The cogging of the steel ingots is done in a reversing mill driven by a pair of engines on Ramsbottom's reversing principle; and from the cogging mill to the circular saw which cuts them in two the ingots are conveyed along the floor by means of a series of rollers driven by an engine. In the rail mill the blooms are hauled out of the heating furnace by hydraulic gear; the tongs attached to the bloom are hooked to a chain that is wound up on a drum by means of a hydraulic cylinder, the ram of which carries a rack gearing into a pinion on the drum shaft. The pair of non-condensing engines driving the rolling mill, having 45 in. cylinders with 10 ft. stroke, coupled at right angles and making 24 rev. per min., with their massive framing and gearing, were described at a former meeting (see Proceedings Inst. M. E. 1857 page 112); also the large non-condensing blowing engine, which has a steam cylinder of 55 in. diameter and 13 ft. stroke, and a blowing cylinder of 144 in. diameter and 12 ft. stroke, making 20 rev. per min. and delivering about 44,000 cub. ft. of air per min. at a pressure of 3¼ lb. per sq. in. For conveying heavy loads of materials

from one part of the works to another at a slow speed and over steep gradients of 1 in 40, small geared locomotive engines are employed, having a single cylinder mounted on the top of the boiler, and driving the trailing axle by gearing from an independent crankshaft. The Dowlais Iron Works were established about 1750, and the number of persons now employed in the ironworks and collieries is between 11,000 and 12,000. The Members were entertained at luncheon at Dowlais by Mr. George T. Clark; and returned to Cardiff in the evening viâ Bargoed and Rhymney Valleys, visiting on the way the ruins of Caerphilly Castle.

On Friday, 7th August, an Excursion was made by the Members by special train from Cardiff to visit the Landore Siemens-Steel Works, the Morfa Copper Works, and the Landore Tinplate Works, near Swansea, and the Mwyndy Iron Ore Mine near Llantrissant.

At the Landore Siemens-Steel Works the Members were received by Mr. Siemens and the Managing Director, Mr. D. M. Gordon, at the new works. The regenerative gas furnaces for the Siemens-Martin process of steel manufacture are arranged in two rows of eight each, along the opposite sides of the casting pit, over which works a steam travelling crane; and along the centre of the pit is an elevated railway, on which run the wagons that receive the ingots, and also a portable steam crane. On the floor of the pit are laid rails for running the casting ladle under the mouth of each furnace and conveying it thence over the ingot moulds, which are arranged in straight rows in the bottom of the pit. Each furnace is capable of working 6-ton charges; and the old works adjoining contain eight similar furnaces. The charge consists of about 6 tons of pig iron and scrap, the proportion varying from 2 to 4 tons of either; sometimes the quantity of pig is the greater, and sometimes the quantity of scrap, according as they happen to be available.

To this is added iron ore sufficient to oxidise the carbon and silicon in the pig iron (African ore was used at the time of the visit), after which about 8 per cent. of spiegel is added, and the charge cast; the result is generally a quantity of steel equal to or slightly exceeding the weight of the pig, scrap, and spiegel together, the iron from the ore replacing the loss of the impurities in the pig &c. When working without scrap, the charge consists of about $5\frac{1}{2}$ tons of pig iron, with sufficient ore as before to oxidise the carbon and silicon; after which spiegel is added, as in the mixed charges. The melting of the bath of pig iron previous to charging the steel scrap occupies from 3 to 4 hours, and the whole time of working off a charge is about 10 hours. In the rolling mill the reheating furnaces are all on the regenerative principle, heated by gas, those for the rail mill being 21 ft. long inside, with four doors for charging and withdrawing the blooms. There are five 8-ton single-acting blooming hammers with 32 in. cylinders and 7 ft. stroke. The rail mill is driven by a reversing engine having a pair of 35 in. cylinders with 4 ft. stroke, geared to make $3\frac{1}{4}$ rev. to 1 rev. of the rolls. The tyre mill on the floor level is driven by gearing from a pair of vertical engines half sunk below the floor. The bar mill and wire mill are driven by a pair of vertical engines with 30 in. cylinders and 4 ft. stroke. In the wire mill the steel wire is brought down from $1\frac{1}{8}$ in. to $\frac{1}{4}$ in. diameter in fourteen passes through the rolls, and the handling of the wire is managed with so much dexterity by the men that during the latter part of the rolling there are five bends in between the rolls at once, so that the single wire is undergoing five different degrees of reduction simultaneously at five different points of its length. Two close-topped blast furnaces supply the pig-iron for the steel-making furnaces; one is 66 ft. high and 19 ft. diameter at the boshes, and the other 65 ft. high and 18 ft. diameter. They are supplied with hot blast by three regenerative firebrick stoves 50 ft. high, heated by gas obtained from separate gas producers, which contains much less dust than the gas taken off from the blast furnaces, and by its use therefore the stoves are more easily kept clean; the furnace gas is used for heating the steam boilers only, for which purpose a dearer

description of coal would have to be used than suffices for the producers. Each of the three hot-blast stoves in succession is kept on blast for $1\frac{1}{2}$ hour at a time, and is then heated up again by the gas for 3 hours. The furnaces are blown with six tuyeres each, by a pair of vertical condensing engines having 45 in. steam cylinders, 100 in. blowing cylinders, and 5 ft. stroke, working with 40 lb. steam and giving a pressure of blast of $4\frac{1}{2}$ lb. per sq. in.; the steam cylinders have double-beat Cornish valves worked by cams. The coke ovens and ore heaps are on high ground at the level of the railway, about 12 ft. below the tops of the blast furnaces, to which the materials are raised by a direct steam lift with 24 in. ram, worked with 30 lb. steam. The coke ovens are arranged in double rows, between which runs an endless chain worked by an engine; and any oven is drawn by attaching the rake to a chain passing round a sheave in front of the oven and hooked to the endless chain. The charging of the ovens is at present done by hand, but arrangements for charging from the top are in progress; and the usual charge in each oven is $4\frac{1}{2}$ tons of coal, which is kept in the oven three days and nights, the loss amounting to only 20 per cent. of the weight charged into the ovens; smaller charges are burnt two days and nights, with a loss sometimes reaching 27 per cent. The coke produced is of a superior quality, containing only 8 per cent. of ash. The bricks for lining the steel-making furnaces are made from selected stones consisting of almost pure silica, and contain 98 per cent. of silica, the remaining 2 per cent. being alkaline matter. The stones are first broken in a stone-breaking machine, and then crushed between rolls. Carr's disintegrator is also used for reducing the stone delivered from the stone-breaker, but the material thus pulverised is too fine for brick-making by itself, and is only used for mixing with the coarser crushed stone from the rolls. This mixture is then further mixed with lime-water, and pressed in moulds worked by hand. The bricks thus made being very tender are carefully placed in a drying shed heated by flues under the floor, and are afterwards stacked and burnt for about five days in beehive kilns, each containing about 33,000 bricks; they are then sufficiently hard and tenacious

to stand much rough usage. The Members were entertained at luncheon at the Works by Mr. Siemens.

At the Morfa Copper Works, Landore, belonging to Messrs. Williams Foster and Co., the Members were received by the Manager, Mr. John Cady. The principal ore smelted is the ordinary yellow copper ore (copper pyrites), which is the most abundant ore of copper, and is a sulphide of copper and iron, the purest qualities containing about 35 per cent. of copper with 35 per cent. of sulphur and 30 per cent. of iron; but the usual proportion of copper is not more than from 5 to 13 per cent., and the ore generally contains more or less sulphur, with arsenic, quartz, and other impurities. The smelting of the ore involves six successive processes of calcining and melting, some of which have at times to be repeated. In the first process a charge of about 80 cwt. of clean ore in a rough powdered state is roasted in a reverberatory furnace or calciner, having a hearth about 18 ft. long and 15 ft. wide; after being exposed to a gentle heat for about 12 hours, during which it is stirred at intervals of 2 hours, the roasted ore, having now lost much of its sulphur and arsenic, is raked out of the furnace to cool, and wetted with water. In the second process a charge of 22 cwt. of this roasted ore is smelted in another reverberatory furnace having a hearth of coarse sand, 11 ft. long and 7 ft. wide, sloping towards the door; the smelting takes about 4 hours, slags and fluxes being added as required, according to the quality of the ore. When the charge is all melted, the slag on the top of the metal, which contains earthy matter, quartz, and the chief part of the iron, and also from $\frac{1}{4}$ to $\frac{1}{2}$ per cent. of copper, is skimmed off by a rabble and drawn out into a sand bed; the melted metal is allowed to remain in the furnace, and repeated charges of roasted ore are put in and treated in the same way, until the melted metal rises as high as the bridge at the door; the tap hole at the side is then opened, and the melted metal run off direct into a tank of water, whereby it becomes granulated. The metal thus obtained, called "coarse metal" or "mat," is an alloy of all the metals in the ore with sulphur, and contains about 33 per cent. of copper, or about four

times the original proportion of copper in the ore, the remaining 67 per cent. being chiefly iron and sulphur. In the third process the mat is roasted in a large furnace like that used in the first process; the charge consists of 80 cwt. of granulated metal or mat, and is kept in the furnace 24 hours, being repeatedly stirred; the metal is afterwards drawn out into a vault under the furnace and oxidised by exposure, the rest of the iron contained in it being thus converted into oxide. The fourth process consists in smelting this metal in charges of 46 cwt. at a time, each charge occupying from 5 to 6 hours; the metal is run out at every second charge into sand beds, and is now a very rich mat, called "fine metal," containing about 66 per cent. of copper. In the fifth process the fine metal is roasted and smelted in a large furnace to get rid of the remainder of the sulphur; a charge of 50 to 60 cwt. after being melted is exposed for 4 hours to a gentle heat, which is afterwards increased to drive off the remainder of the sulphur; the slag is repeatedly skimmed off the melted metal, which is run out into sand moulds, and is called "rotten" or "blistered copper," containing 94 to 96 per cent. of copper. This is then refined and toughened in the sixth process, a charge of about 8 tons being exposed in a smelting furnace for 12 or 16 hours to a roasting heat, then melted, skimmed of slag, and worked as clean as possible. After it has been about 24 hours in the furnace, samples for testing are taken at frequent intervals in small iron ladles; if the metal is fine enough, it settles down considerably in the ladle on cooling; but if it swells up and shows dark veins or marks, it requires further "fining." When sufficiently refined, the toughening is effected by covering the surface of the melted copper with powdered charcoal or anthracite coal; and in order to accelerate the process and to get rid of the last traces of oxide, the metal is also "poled" or stirred diligently for about half an hour with a pole of green wood; this produces a strong ebullition, thereby raising any remaining impurities to the surface, where they are skimmed off, leaving the metal soft, tough, and of a light red colour. The duration of the poling has to be carefully regulated, for if continued too long

or not long enough, the copper is of brittle quality in either case, and is said to be "overpoled" or "underpoled" respectively; when a test sample of the copper hammered cold on the anvil does not crack on the edges, and the colour and grain are good, it is considered sufficiently refined and toughened. The finished metal is ladled out of the furnace by iron ladles, and is poured into cast-iron moulds to form cakes, bars, or ingots of "fine copper," for rolling or casting. The copper rolling-mill is supplied with cakes varying from 1 cwt. to nearly 20 cwt., the smaller sizes for making copper sheathing for ships, and the heavier cakes for making large plates for locomotive fireboxes &c. The copper hammer-mill contains a steam hammer, by which these locomotive plates are hammered and flanged, and large bottoms for breweries and distilleries are made, as also large bowls and sugar pans. The yellow-metal mill is principally engaged in the rolling of ships' sheathing, and of large square sheets for export. There is also a train of rolls for making bars and bolts of both copper and yellow metal.

At the Landore Tinplate Works, where the Members were received by the Manager, Mr. Richard Hughes, the iron, which is required to be of very uniform and specially good quality, is all made on the premises from the best pig iron; this is fused in a coke refinery, then remelted and worked in a charcoal refinery, and then stamped out under a steam hammer into large cakes or "stamps" of about $1\frac{1}{2}$ to 2 in. thickness; these are reheated in hollow fires, forged under heavy helves, and rolled into bars, which after being cut to the proper length are rolled down into very thin plates, eight times the thickness of those ultimately required. Each plate is then folded into eight, and reheated, and the whole pile is rolled again down to the same thickness as before; the ends being sheared, the thin sheets are separated, pickled in dilute sulphuric acid, washed, annealed in closed boxes in a furnace at a dull red heat, and planished by rolling cold. After a second annealing, pickling, and washing, they are placed in a bath of melted palm oil, and then dipped successively into three baths of melted tin; the last of

these contains a purer quality of tin, and has a pair of finely finished rollers immersed in it, between which each plate passes in quitting the bath; by this means the superfluous tin which formerly used to collect along the bottom edges of the plates is wiped off and saved. The tinplates are then dipped in bran or "sharps" and wiped, which gives them a final polish; and they are packed in boxes according to size and quality. "Terne" plates are made in the same manner, but are coated with a mixture of about $\frac{2}{3}$ lead and $\frac{1}{3}$ tin. To show the extreme tenuity to which the iron plates can be reduced by the rolling, specimens were exhibited of plates rolled cold in the planishing rolls, of the following dimensions and weights:—

Size of Plate. in. in.	Total Weight. grains.	Weight per sq. ft. grains.
$6\frac{3}{4} \times 4\frac{1}{2}$	6·5	31·1
$9\frac{1}{4} \times 9$	27·0	46·8
$41 \times 8\frac{3}{8}$	1330·8	558·2
$45 \times 9\frac{5}{8}$	1389·3	462·0

The thinnest of these plates was consequently not more than 0·00011 in. or 1-8900th in. thick, while the largest plate, of 45 in. length, was 0·00166 in. or 1-600th in. thick, which was a sample of ordinary manufacture.

In returning from Landore to Cardiff, the Members visited the Mwyndy Iron Ore Mine, near Llantrissant, where they were received by the Manager, Mr. William Vivian, who gave a description of the mine, and an account of the early opencast mining for iron ore and the manufacture of iron with charcoal, which were carried on in that locality several hundred years ago, until prohibited by an act of parliament forbidding the further use of the neighbouring woods for the requisite supplies of fuel; and a specimen of iron of excellent quality was shown, which had been produced at the time of those early workings, the name "Mwyn-dy" meaning "mineral house." About sixteen years ago a discovery of ore in the adjoining property led to the finding of ore in this mine also, and workings were commenced upon it. The deposit consists of brown hæmatite iron ore, occurring in a large

bed or mass, between the carboniferous limestone on which it rests, and a bed of conglomerate. It lies immediately south of the edge of the South Wales coal basin, the thin shales overlapping the limestone close to the ore. The bed of ore was in some places from 35 to 40 ft. thick, and it dips north at an angle of about 45 degrees. Like most other deposits of hæmatite iron ore in the same formation, it is found to be very irregular, large masses of ore being suddenly cut off by intervening bosses of limestone. This necessitates the employment of not less than one third of the miners upon "dead work," exploring, and making communications for ventilation and for the conveyance of the ore; the total number of men employed is about 280. The mine is worked both opencast and by mining underground, the extent of the workings being very considerable. The vertical depth to the present deepest point is 280 ft. from surface; and the water is pumped by two engines, each of which in winter raises upwards of 1,000 gall. per min., one of them being arranged to work on the dip. The ore is very variable in hardness, and a great deal of it requires blasting; from the levels it is brought out by horses to the vertical shafts and inclined planes, and on reaching the surface is tipped direct into the railway wagons, if sufficiently pure; but if not, it is first dressed by hand labour, being broken by hammers and then picked by hand to separate the iron pyrites and other impurities. The total quantity of iron ore raised and sold has been over 620,000 tons, and the mine is at present in active work, yielding about 5,000 tons of ore per month. The quality of the ore is useful, yielding from 45 to 48 per cent. of metallic iron; it contains some silica. This and the Bute mine adjoining are the only hæmatite iron mines of importance in the district, and they possess the advantage of being within easy distance by rail from many of the South Wales blast furnaces. The Members were invited to refreshments at the mine by the Mwyndy Iron Ore Company; and returned in the evening by special train to Cardiff.

On Saturday, 8th August, an Excursion was made by the Members by special train from Cardiff to Harris' Navigation Coal Co.'s Pits, near Quaker's Yard, where the diamond rock-drilling machine is being employed for sinking two shafts. They were received by the Managing Director, Mr. Frederick W. Harris, and the other Directors, and by Messrs. Brown and Adams, under whose direction the works are being carried out. The pits are being sunk for the purpose of working a coalfield of about 2,800 acres, and the coal expected to be worked is the Aberdare Upper 4 Feet seam and the other White-Ash coal measures of South Wales, the estimated depth to the former being over 600 yards. The two pits are 17 ft. diameter and 60 yards apart, and have reached a depth of 128 yards since first starting fifteen months ago; the sinking is at present in the Pennant rock, the thickness of which is estimated to be from 300 to 400 yards. At about 200 yards depth a workable bituminous seam is expected, called the Brithdir seam, which is one of the blackband or lower Pennant series. The rock-drilling machine consists of a long rectangular cast-iron framing, extending across the pit, and mounted on a vertical centre bar, on which it can be turned round to face in different directions. The two opposite sides of the framing form vertical slide-beds, each carrying four revolving vertical drill spindles placed at any desired distance apart, so that eight drills can be at work simultaneously if required, the spindles being driven by bevil gearing from a central engine worked by compressed air. The lower end of each spindle is enlarged to $2\frac{1}{4}$ in. diameter and is made tubular, the bottom annular face having four diamonds embedded in it. The machine was shown at work above ground on a block of Pennant stone $11\frac{1}{2}$ in. thick, through which a $2\frac{1}{4}$ in. hole with $\frac{3}{4}$ in. core was drilled in $4\frac{1}{2}$ min. In sinking the pits the practice is to bore a set of thirty holes at the bottom of one pit to a depth of about $4\frac{1}{2}$ ft., and then remove the machine to bore in the other pit while the holes in the first are charged and fired, dynamite being employed for the blasting. The compressed air at 40 lb. per sq. in. is supplied by a compressor having a pair of vertical overhead cylinders, the inlet valves being placed in the pistons; the compressor is

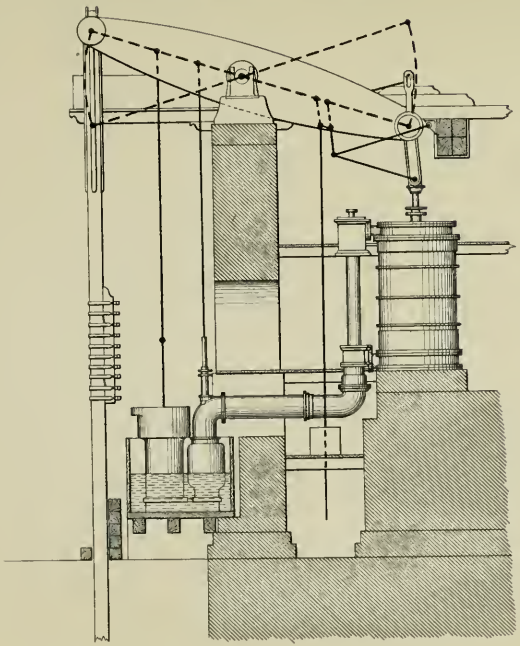
driven by a horizontal engine with 25 in. cylinder geared 2 to 1. A pair of locomotive engines suitably fixed, of 50 H. P. each, are employed to drive the temporary winding gear, their driving axles being extended and coupled direct to the drums. The Members were invited to luncheon at the works by the Directors of the Company.

The special train then proceeded to Newport, stopping on the way at the Crumlin Viaduct, and the Members were conducted through the whole length of the viaduct underneath the roadway by the District Superintendent of the Great Western Railway, Mr. Peter Donaldson. The viaduct crosses the valley of the river Ebbw in seven spans of 150 ft. each, the total length being 1050 ft. and the greatest height 200 ft. The piers are formed of hollow cast-iron columns, 17 ft. high and 1 ft. diameter, built up in successive tiers, with fourteen columns in each tier, and the piers taper upwards from an area of 27 ft. by 60 ft. at the base of the highest pier to 18 ft. by 30 ft. at the summit of each; the columns are fitted into one another by socket joints, and are connected in each tier by horizontal cast-iron girders, and by horizontal and vertical wrought-iron tie-rods tightened by wedges. The main girders are Warren trusses, each 150 ft. long and $14\frac{1}{2}$ ft. deep; the compression beam, forming the top member of the girder, is a riveted box-girder 14 in. deep and 9 in. wide, formed of plates of varying thicknesses; the tension member consists of four wrought-iron bars, of 6 in. $\times \frac{5}{8}$ in. average section. There are four girders in each span, carrying a double line of rails; they are supported by the ends of the compression beam resting upon a sliding block in a saddle casting on the top of the piers, to allow for expansion and contraction; the extreme difference of length in each span between summer and winter does not exceed $1\frac{1}{3}$ in. The viaduct was completed in 1856 at a cost of £60,000, including three additional spans of the same length in the adjoining smaller viaduct; but the subsequent further expenditure in 1868, for strengthening the girders, and substituting a wrought-iron floor with cross girders and rail bearers, in place of the timber with which the

viaduct was originally covered, amounted to about £15,000, including painting.

MINE PUMPING ENGINES.

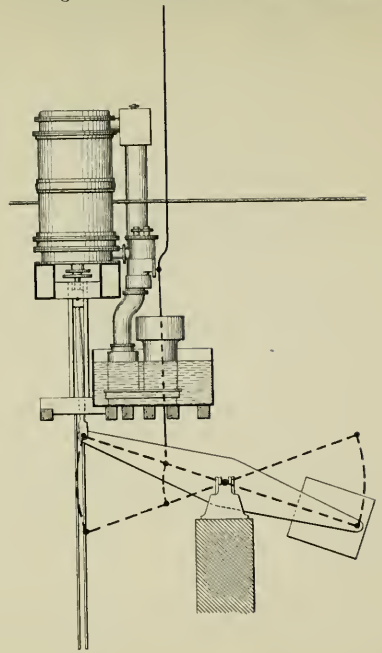
Fig. 1. *Cornish Beam Engine.*



(Proceedings Inst. M.E. 1874.)

Scale 1/200 th

Fig. 2. *Cornish Bull Engine.*



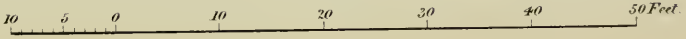


Plate 77.

Fig. 3. *Rotary Double-Acting Beam Engine.*

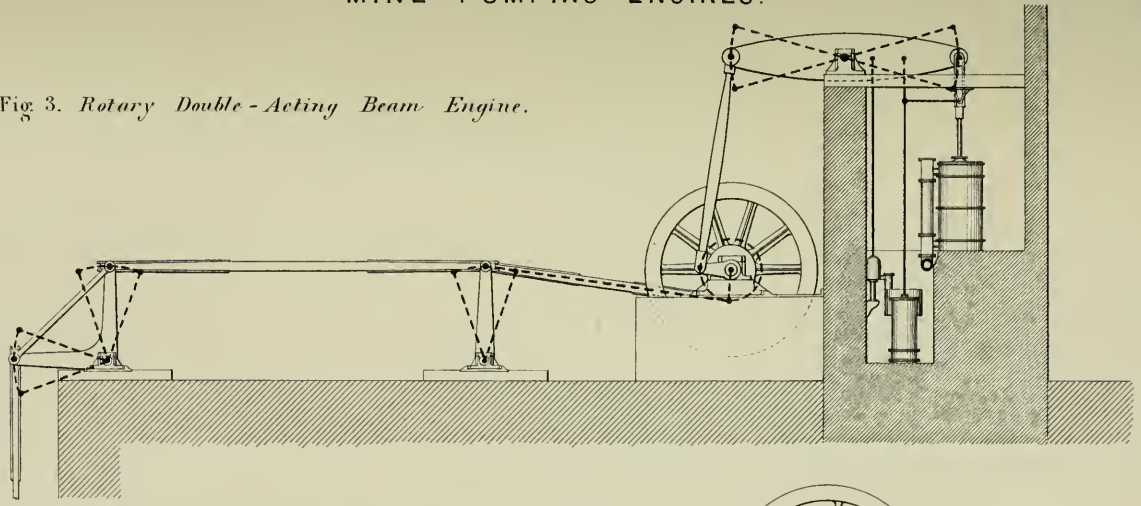
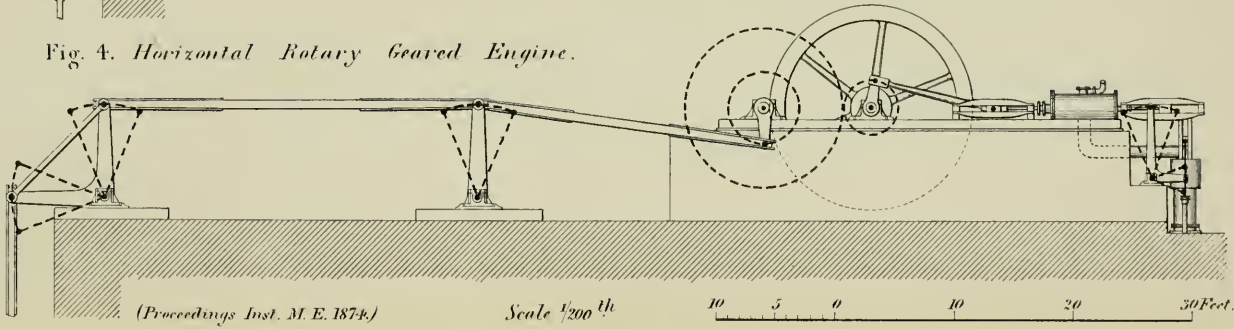


Fig. 4. *Horizontal Rotary Geared Engine.*



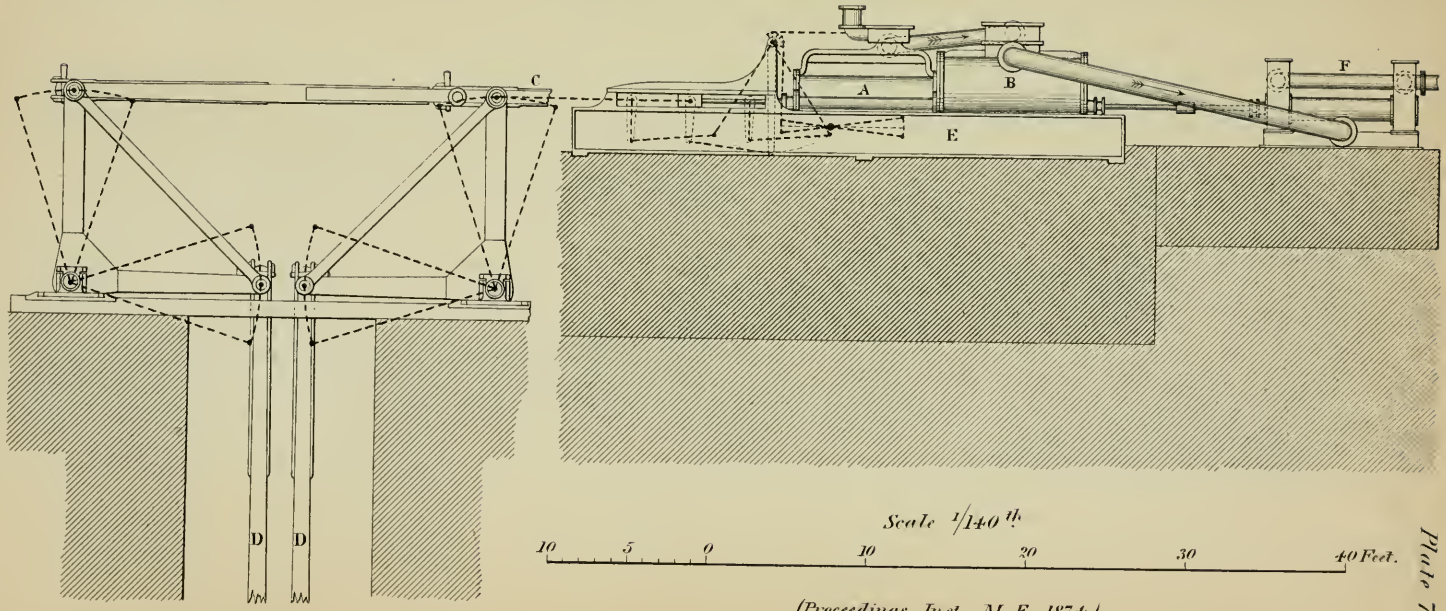
(Proceedings Inst. M. E. 1874.) Scale 1/200th

Plate 78.

MINE PUMPING ENGINES.

Compound Differential Engine.

Fig 5. *Side Elevation.*



(Proceedings Inst. M. E. 1874.)

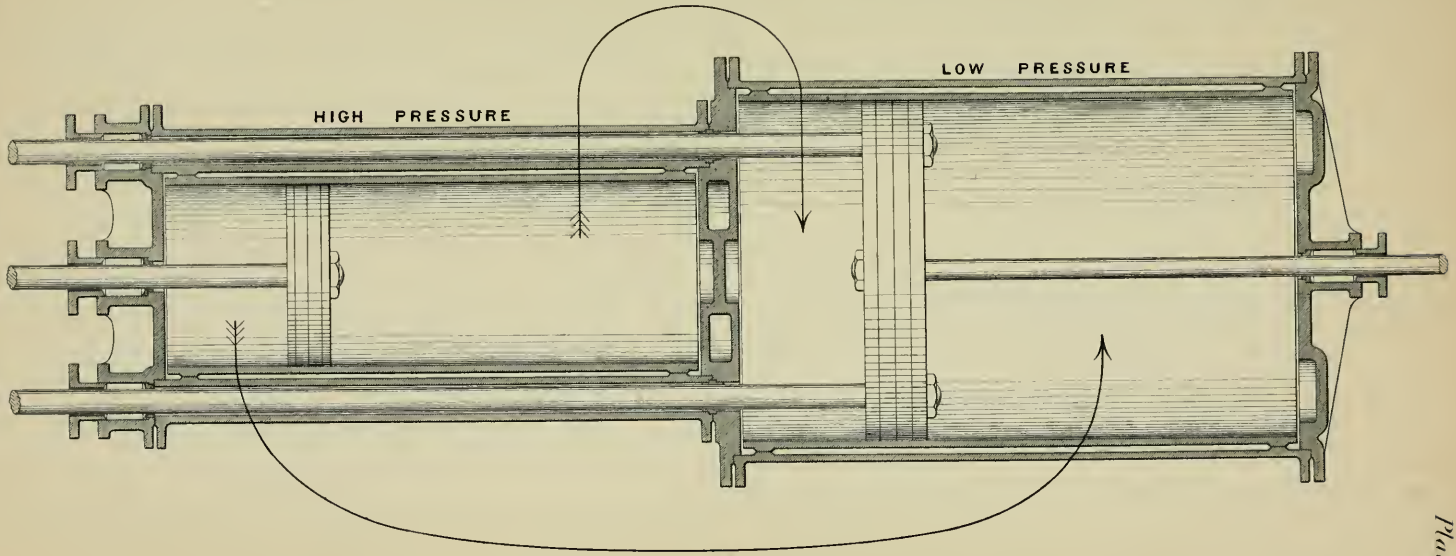
Plate 79.

MINE PUMPING ENGINES.

Plate 80.

Compound Differential Engine.

Fig. 6. *Sectional Plan of Steam Cylinders.*



(Proceedings Inst. M.E. 1874.)

Scale $\frac{1}{36}^{th}$

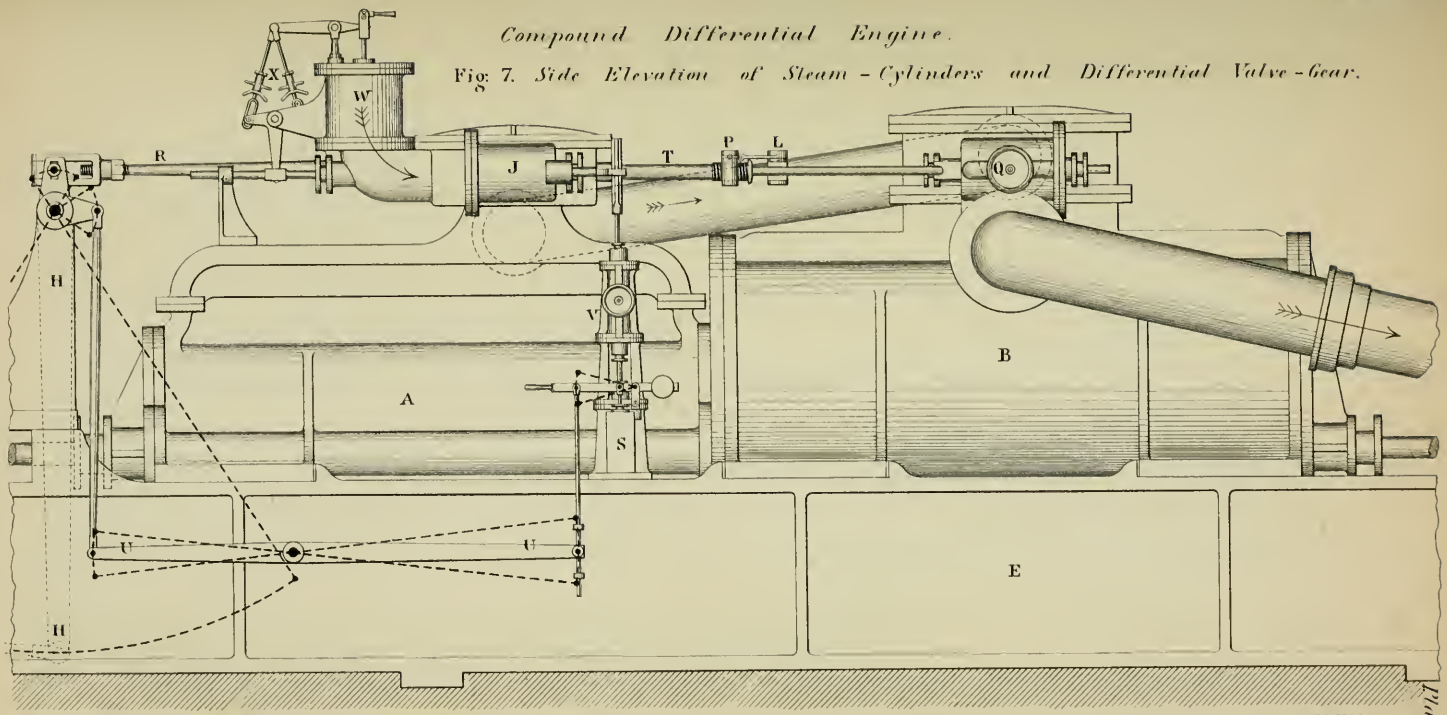
Ins. 12 6 0 1 2 3 4 5 6 7 8 9 10 *Feet.*

Plate 80.

MINE PUMPING ENGINES.

Compound Differential Engine.

Fig. 7. *Side Elevation of Steam-Cylinders and Differential Valve-Gear.*



(Proceedings Inst. M.E. 1874.)

Scale 1/36th

In. & Ft. 12 6 0 1 2 3 4 5 6 7 8 9 10 Feet.

Plate 81.

MINE PUMPING ENGINES.

Compound Differential Engine.

Fig. 9.
Transverse Section of High-Pressure Slide-Valve.

Fig. 10. *Transverse Section of Low-Pressure Slide-Valve.*

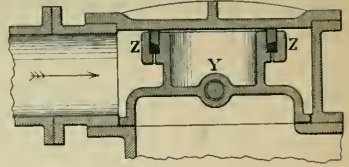
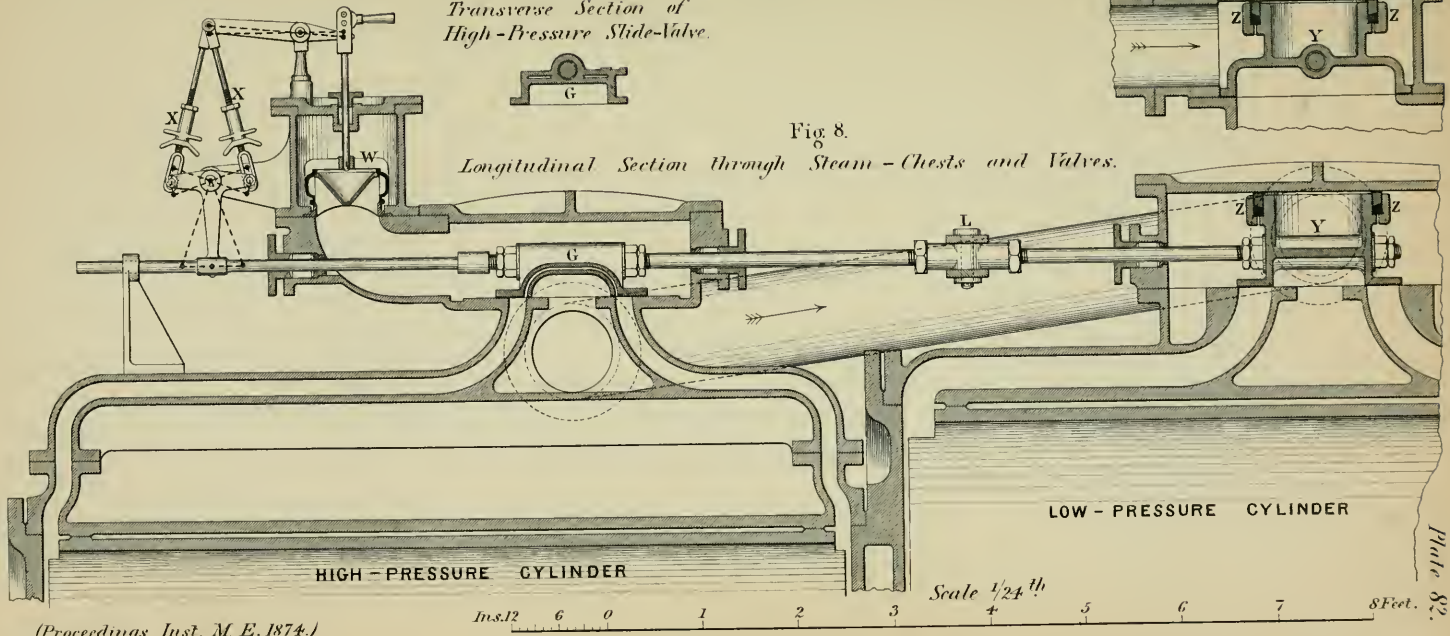


Fig. 8.
Longitudinal Section through Steam-Chests and Valves.



(Proceedings Inst. M. E. 1874.)

Plate 82.

Compound Differential Engine.

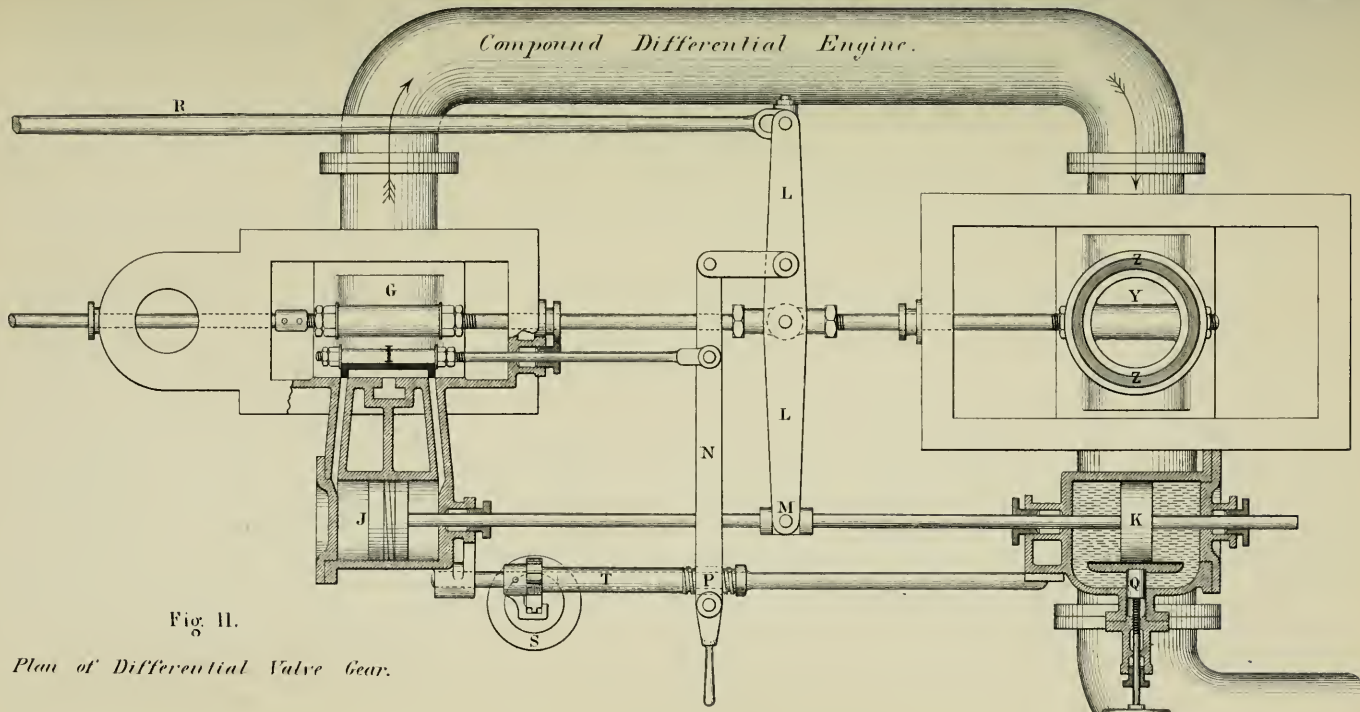


Fig. 11.

Plan of Differential Valve Gear.

(Proceedings Inst. M. E. 1874.)

Scale 1/24th

Ins. 12 6 0 1 2 3 4 5 6 Feet.

Plate 83.

Compound Differential Engine.

Diagrams illustrating action of Differential Valve Gear.

Fig. 12.
Beginning of Engine Stroke.

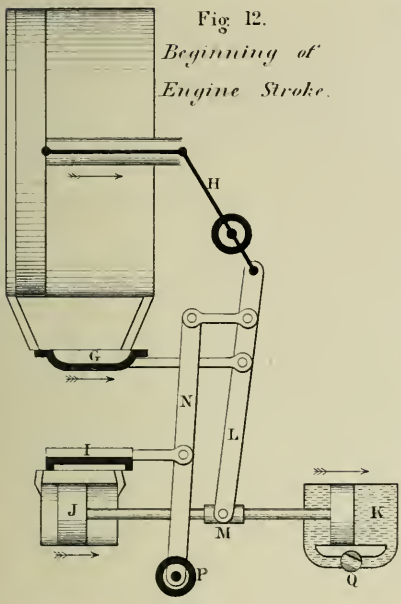


Fig. 13.
Light Load, Early Cut-Off.

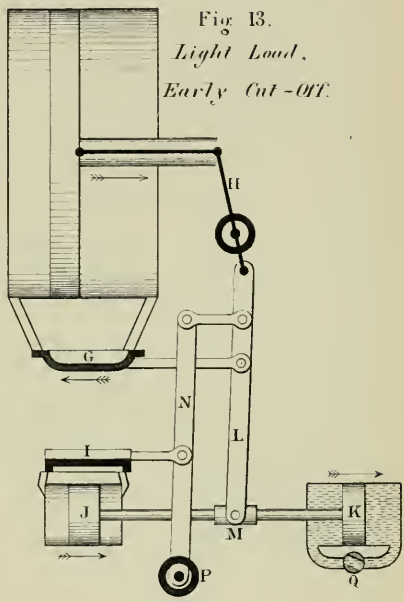


Fig. 14.
Heavy Load, Late Cut-Off.

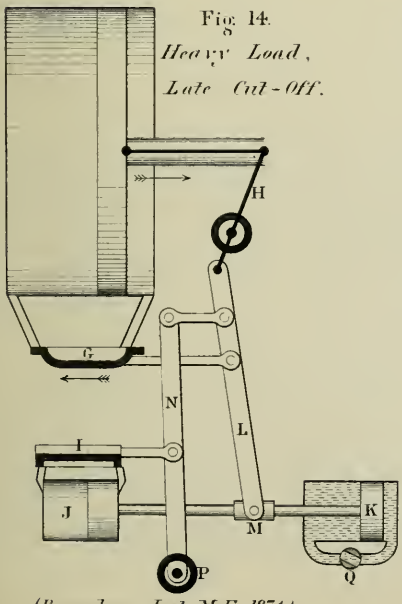
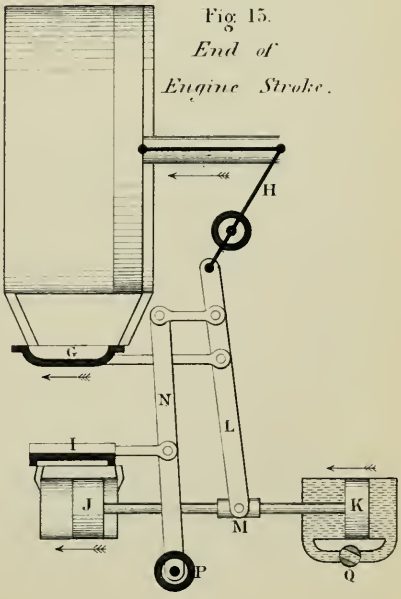


Fig. 15.
End of Engine Stroke.



(Proceedings Inst. M.E. 1874)

MINE PUMPING ENGINES. *Plate 85.*

Fig. 16. *Compound Differential Engine and Hydraulic Engine applied underground.*

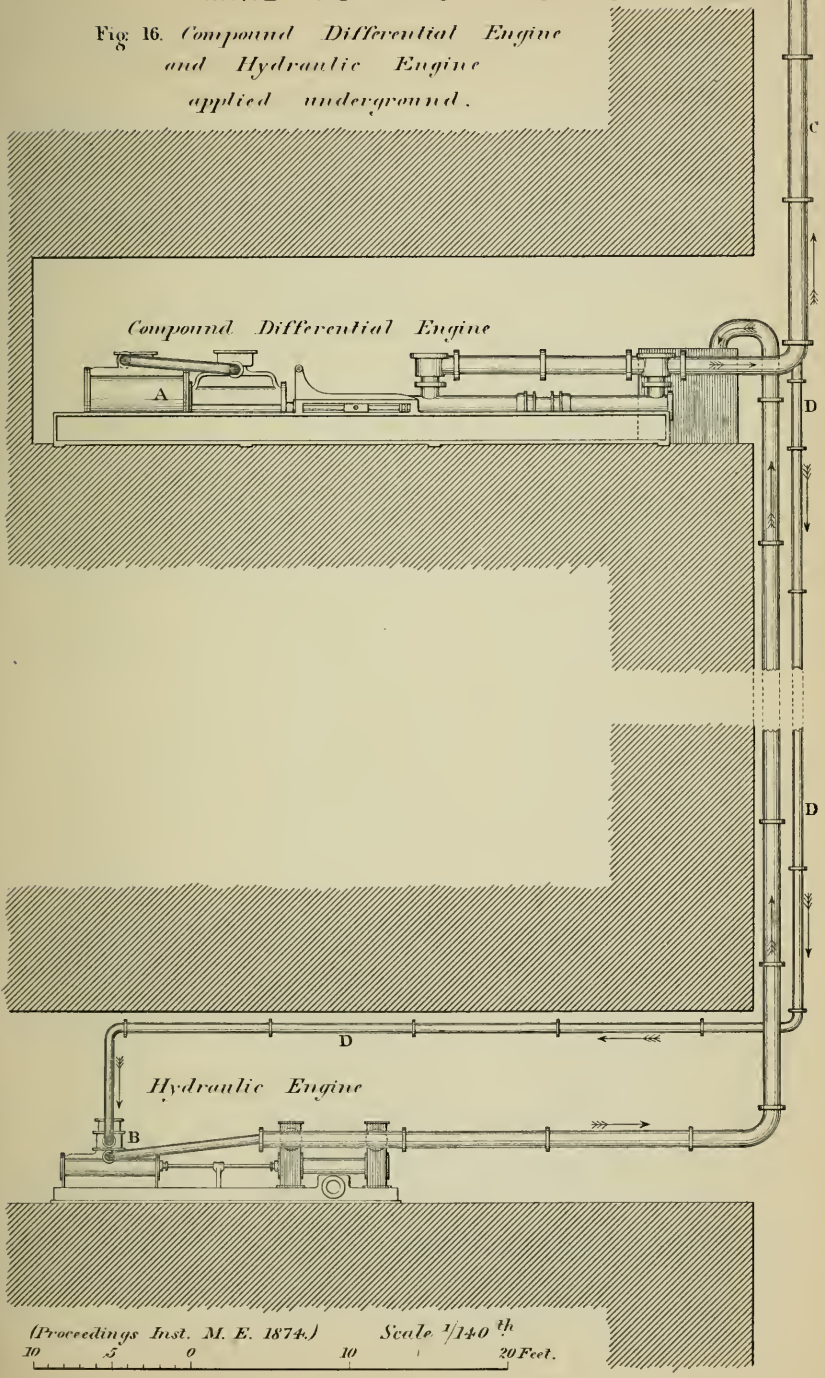
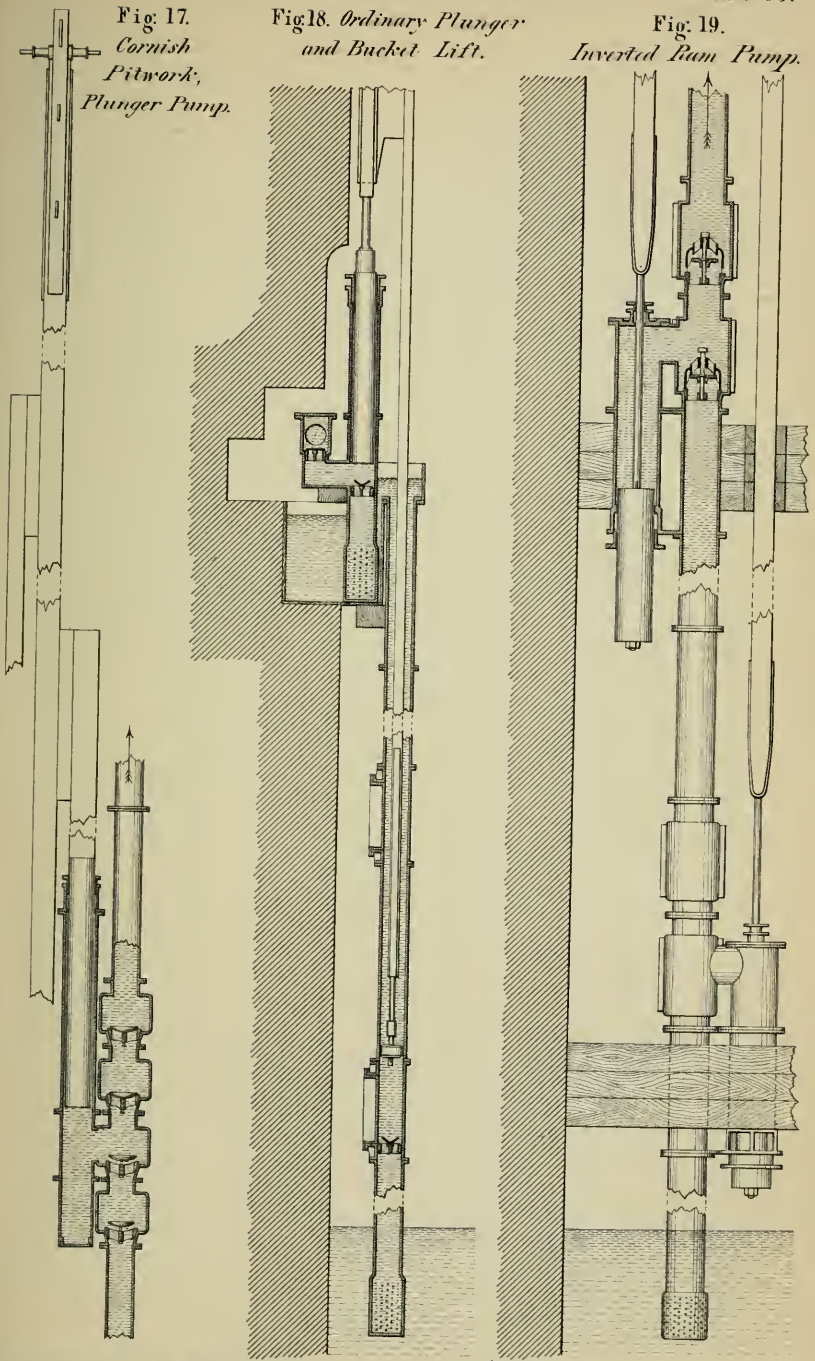


Fig. 17. *Cornish Pitwork, Plunger Pump.*

Fig. 18. *Ordinary Plunger and Bucket Lift.*

Fig. 19. *Inverted Ram Pump.*



(Proceedings Inst. M.E. 1874)

Scale 1/120th.

10 5 0 10 20 30 Feet.

Fig. 20.
Inverted Ram Pump.
Scale 1/32nd.

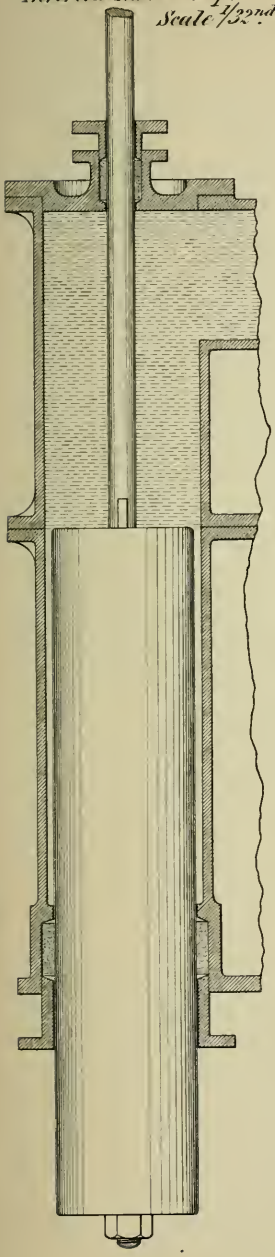


Fig. 21.
Hollow Ram Pump.
Scale 1/32nd.

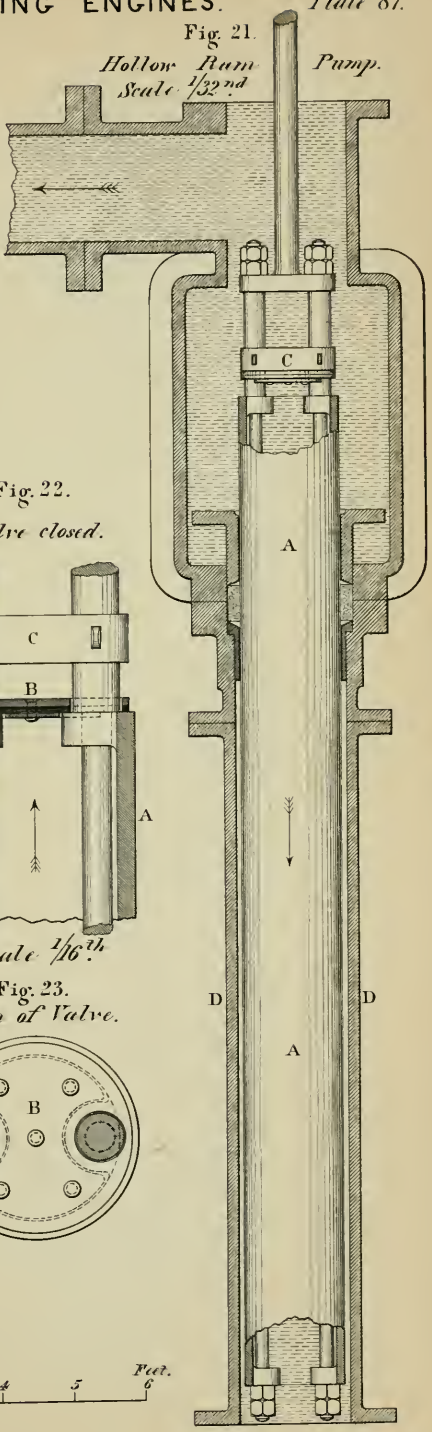
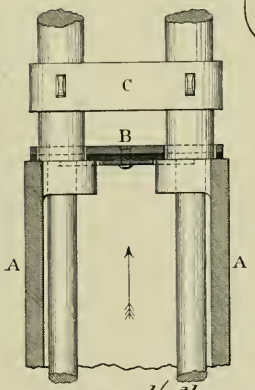
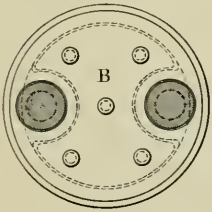


Fig. 22.
Valve closed.



Scale 1/16th.

Fig. 23.
Plan of Valve.



Scale 1/32nd.

Ins. 12 6 0 1 2 3 4 5 6 Feet.

(Proceedings Inst. M.E. 1874)

Fig. 24. *End Elevation.*

Double-acting Ram Pump.
Scale 1/32nd.

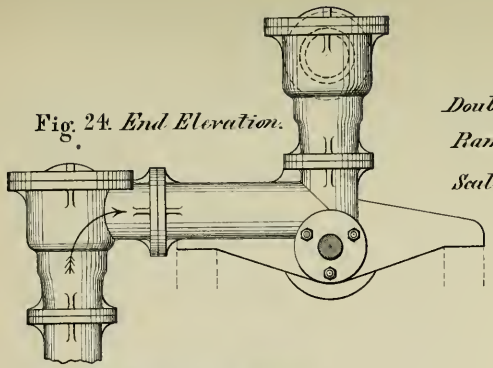


Fig. 25. *Longitudinal Section.*

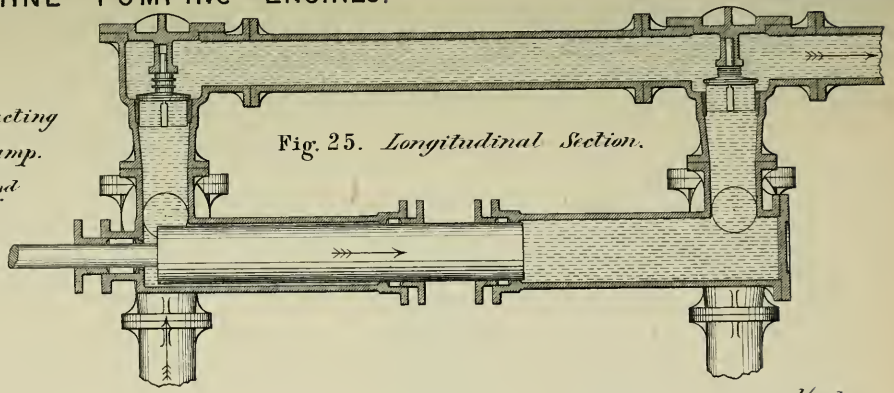


Fig. 28. *Scale 1/4th.*
Enlarged Section of Piston.

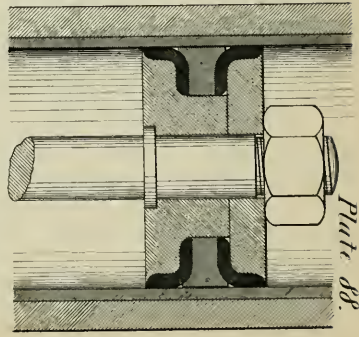


Fig. 26.

Single-acting Ram Pump.

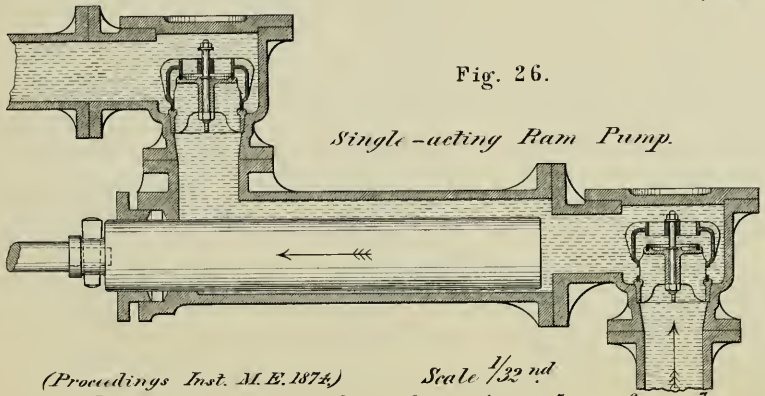
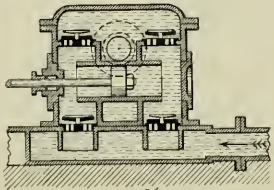


Fig. 27.

Double-acting Piston Pump.



(Proceedings Inst. M.E. 1874.)

Scale 1/32nd

Scale 1/32nd

Ins. 12 6 0 1 2 3 4 5 6 7 8 9 10 Feet.

Fig. 33. *Trevithick's Compound Engine.*

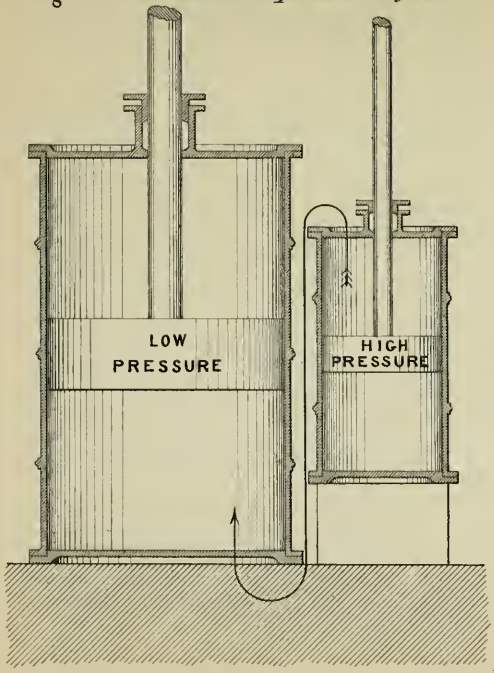


Fig. 34. *Sims' Compound Engine.*

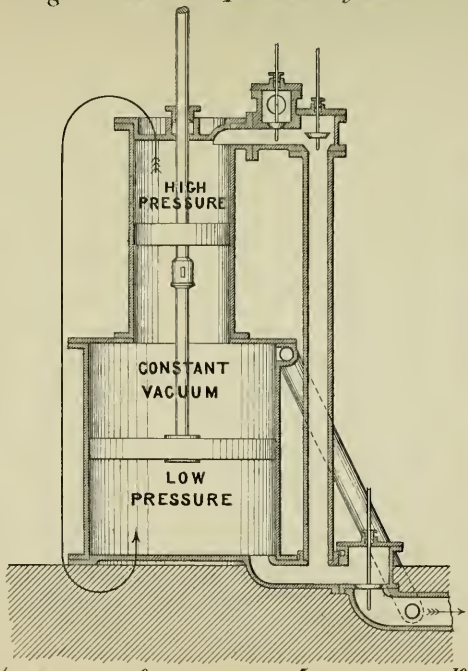
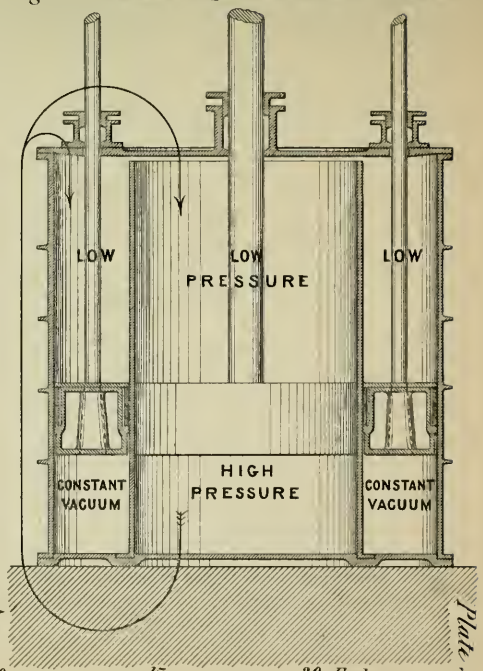


Fig. 35. *Haerlem Compound Cornish Engine.*



(Proceedings Inst. M.E. 1874) *Scale 1/70th.*

0 5 10 15 20 Feet.

Plate 30.

Compound Differential Pumping Engine at Lambton Colliery.
Cylinders $27\frac{1}{2}$ *and* 44 *in. diameter.* 5 *ft. stroke.*
12 *double strokes per min. Condenser disconnected.*

Fig. 36. *Indicator Diagrams from Front End of each cylinder.*
High-pressure cyl. 27·8 *lb. mean pressure* = 60·0 *H.P.*
Low-pressure 3·4 *lb.* = 18·8 *H.P.*
Total power of both cylinders in INWARD *stroke* 78·8 *H.P.*

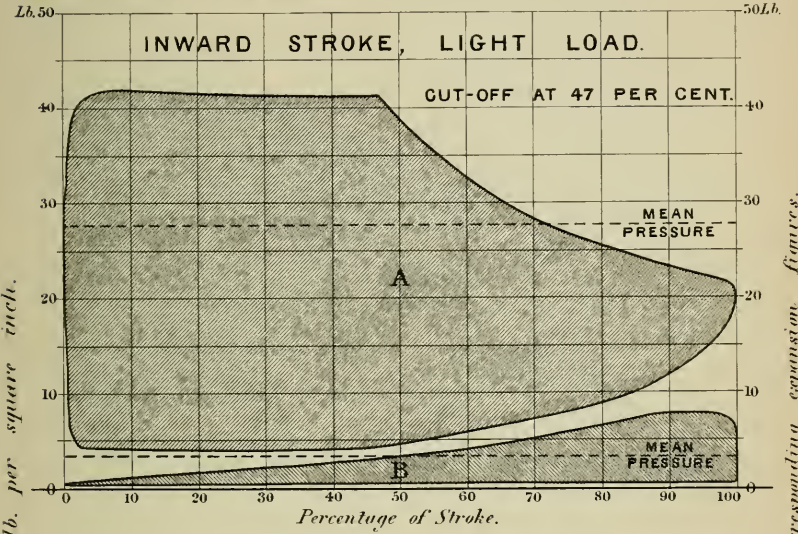
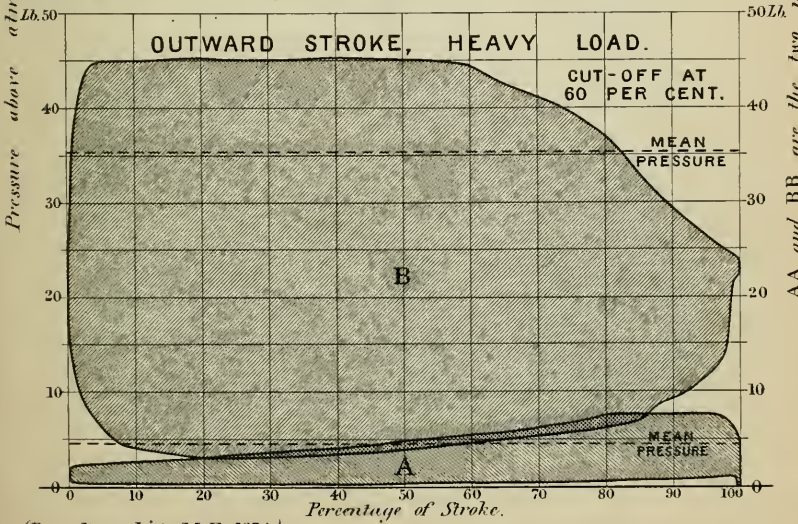


Fig. 37. *Indicator Diagrams from Back End of each cylinder.*
High-pressure cyl. 35·3 *lb. mean pressure* = 76·2 *H.P.*
Low-pressure 4·6 *lb.* = 25·4 *H.P.*
Total power of both cylinders in OUTWARD *stroke* 101·6 *H.P.*



(Proceedings Inst. M.E. 1874.)

Fig. 38. *Indicator Diagram from Cornish Pumping Engine at Grenver and Wheal Abraham Mine, Cornwall. Cylinder 90 in. diameter, 11 ft. stroke. Mean effective pressure 13·8 lb.*

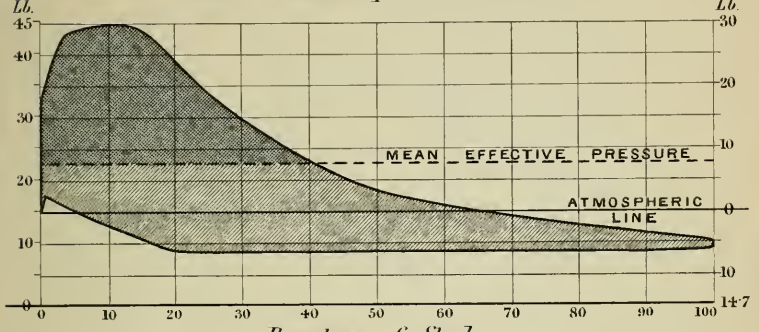
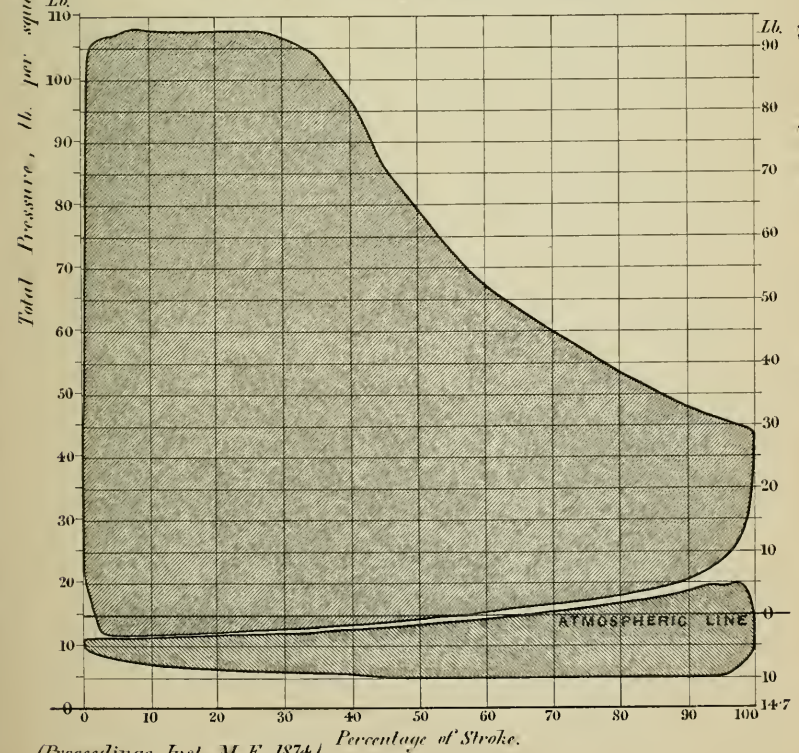


Fig. 39. *Indicator Diagram from Compound Rotary Engine. Cylinders 12 and 28 in. diam. 3 ft. stroke. 50 rev. per min. Boiler pressure 110 lb. Condenser vacuum 10·25 lb.*



(Proceedings Inst. M. E. 1874)

HELICAL PUMP.

Plate 93.

Fig. 1. *Longitudinal Section.*

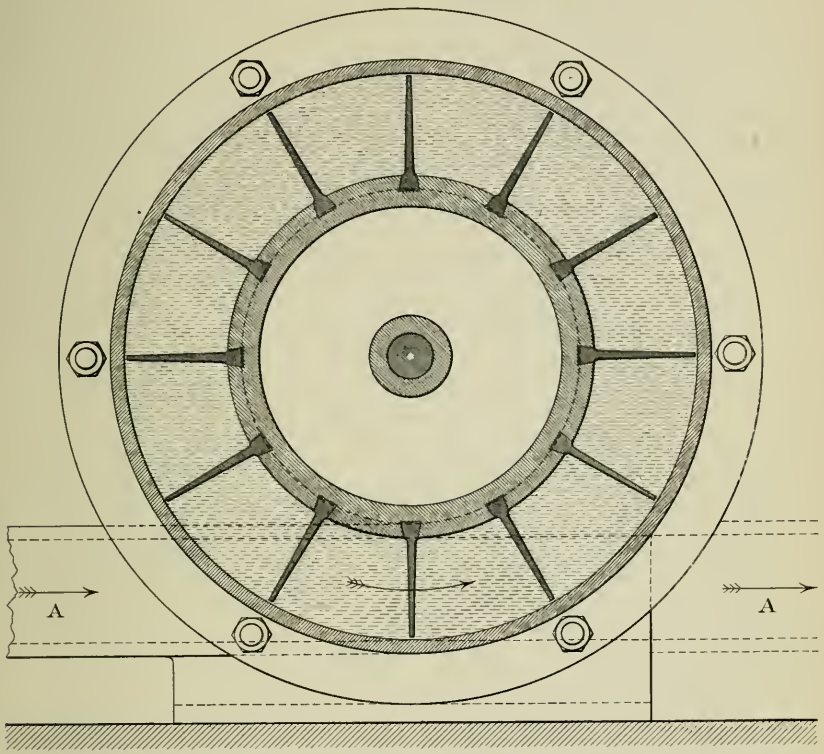
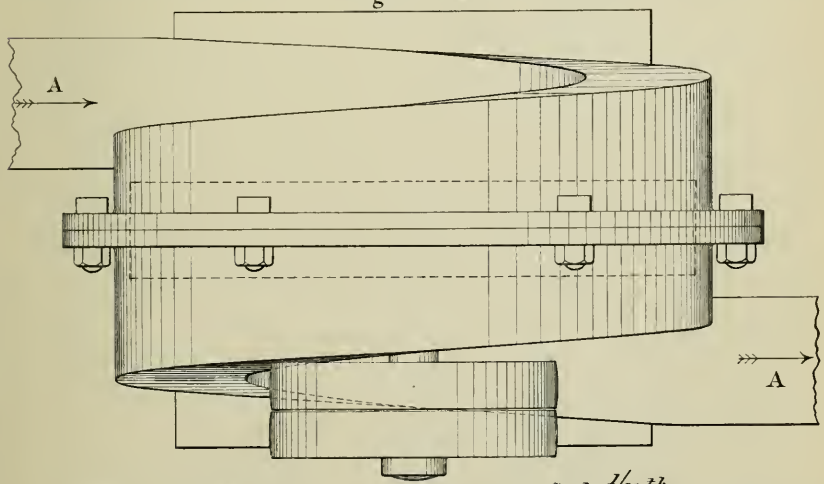


Fig. 2. *Plan.*



(Proceedings Inst. M.E. 1874)

Scale 1/12th

10 5 0 10 20 30 Inches.

PROCEEDINGS.

October 1874.

The General Meeting of the Members was held at the Institution of Civil Engineers, London, on Thursday, 29th October, 1874; Frederick J. Bramwell, Esq., F.R.S., President, in the Chair.

The Minutes of the last Meeting were read and confirmed.

The President:—Before proceeding with the regular business I have a few words to say, and they are sad words. Since the last meeting two of our Members, Sir William Fairbairn and Mr. Sampson Lloyd, have died; and I think you will agree with the Council and with myself, it would not be proper that two such men should pass away from our ranks, without an opportunity being given to the Members to express their sorrow at the loss they have sustained, and also to express their sympathy with the relatives of those who have been taken from us. Sir William Fairbairn's career must be well known to all; it is a most encouraging one to every right-minded and hard-working man, whatever may be his business in life, and still more is it so to those who belong to the profession of the Mechanical Engineer. Fairbairn began life as a working engineer, with no extraneous aid beyond the comparatively limited education which fell to the lot of the son of a small farmer, but with the valuable internal support of a clear and strong mind guided by an honest heart. These aids however are powerful ones, and with them he was enabled to prosper so as to raise himself above his then station; and to go on from rank to rank, until he became the proprietor of a large manufactory and the employer of labour on a great scale. Under these circumstances Fairbairn however did not

devote himself exclusively or even principally to his own aggrandisement or to the acquisition of wealth; but he laboured to elevate our profession by applying science to practice, and he has given to the world the results of his labours, in his writings which furnish text books for every engineer and millwright. Conduct such as this was sure to meet with recognition at our hands and at those of the scientific world. For ourselves, we made him President of this Institution, the highest honour we have in our power to confer; the Royal Society elected him one of their Fellows, the University of Cambridge conferred upon him the degree of Doctor, the Institute of France made him one of its Corresponding Members, and finally Her Majesty was pleased to elevate him to the rank of Baronet. He long lived to enjoy these well-earned honours, and he has died in a good old age. In his case therefore our regret, sincere and deep as it is, is not accompanied by any shock. Advancing years had for some time past prevented him from attending our meetings, and one knew that in the course of nature his death was imminent; but in the instance of Mr. Sampson Lloyd this is not so. He was amongst us only a few weeks ago, at the Cardiff meeting, taking his usual active cheerful part in all our proceedings; and little did any of us think that within so short a time as has passed between that meeting and this he would be taken away. He was for many years the head of a large engineering and iron-making establishment, and was one of our very earliest Members, and although his name was not before the world as was that of Sir William Fairbairn, nevertheless it was well known and most deeply respected by every member of the engineering profession. For years he has been one of our Vice-Presidents, and I am sure I may say that no one has attended more sedulously to the duties of that office than did Mr. Sampson Lloyd. Whenever any question of difficulty arose, his advice was most valued, for it was given temperately and dispassionately; and I am certain that there is hardly anyone whose death would have caused the members of this Institution greater sorrow.

The PRESIDENT moved the following resolution:—"That this meeting desire to express their deep regret at the death of their Past-President, Sir William Fairbairn; and that the Secretary be directed to convey that regret and the expression of their profound sympathy to Lady Fairbairn."

The resolution was seconded by Mr. Siemens and carried unanimously.

The PRESIDENT also moved:—"That this meeting desire to express their deep regret at the death of Mr. Sampson Lloyd; and that the Secretary be directed to convey that regret and the expression of their profound sympathy to Mrs. Lloyd."

The motion was seconded by Mr. Menelaus and carried unanimously.

The PRESIDENT announced that the President, Vice-Presidents, and five Members of the Council in rotation, would go out of office in the ensuing year, according to the rules of the Institution; and that at the present meeting the Council and Officers were to be nominated for the election at the Anniversary Meeting in January next.

The following Members were nominated by the Meeting for the election at the Anniversary Meeting:—

PRESIDENT.

FREDERICK J. BRAMWELL, F.R.S., . London.

VICE-PRESIDENTS.

(*Six of the number to be elected.*)

I. LOWTHIAN BELL, F.R.S, . . Newcastle-on-Tyne.
WILLIAM CLAY, ... Birkenhead.
CHARLES COCHRANE, ... Dudley.
EDWARD A. COWPER, ... London.
THOMAS HAWKSLEY, ... London.
JOHN HICK, M.P., ... Bolton.
WILLIAM MENELAUS, ... Dowlais.
JOHN ROBINSON, ... Manchester.
CHARLES P. STEWART, ... Manchester.
PERCY G. B. WESTMACOTT, . . . Newcastle-on-Tyne.

COUNCIL.

(*Five of the number to be elected.*)

Charles Edwards Amos,	London.
E. Hamer Carbutt,	Bradford.
Edward Easton,	London.
William Froude, F.R.S.,	Torquay.
Frederick W. Kitson,	Leeds.
Walter May,	Birmingham.
Richard Taylor,	London.
Francis W. Webb,	Crewe.

The President announced that the Ballot Lists had been opened, and the following New Members were found to be duly elected:—

MEMBERS.

Thomas John Bewick,	London.
William T. H. Carrington,	London.
William Curry,	Dublin.
Walter Scott Davy,	Sheffield.
George Frederick Deacon,	Liverpool.
John Fielding,	Gloucester.
William Firth,	Leeds.
William George Laws,	Newcastle-on-Tyne.
Edmund Legh Morris,	Stowmarket.
Frederick Henry Ricketts,	London.
James Riley,	Swansea.
Henry Robinson,	London.
Michael Stephens,	Cape of Good Hope.
Percyvale Taylor,	Bristol.
William Henry Thomas,	London.
Edward Warner,	Stowmarket.

ASSOCIATES.

Robert Anthony Hardcastle,	Leeds.
James Hurman,	Cardiff.
Joseph Ellershaw Pepper,	Leeds.

GRADUATES.

JOSEPH STEPHENSON, ... Stoke-upon-Trent.
ARTHUR TAYLOR, ... London.

Mr. J. ROBINSON gave notice that at the ensuing Anniversary Meeting of the Institution in January he should propose the following motion:—"That the Council be empowered to appoint a Meeting in each year to be held in Manchester."

The following paper was then read:—

ON DIRECT-ACTING PUMPING ENGINES AND PUMPS FOR HIGH LIFTS IN MINES.

By Mr. HENRY DAVEY, of Leeds.

The various constructions of Pumping Engines in use for draining mines and other purposes may be classed as single-acting, double-acting, and compound engines; and these are again divided into beam engines, and direct-acting engines, horizontal or vertical.

The *Single-acting* or *Cornish Beam Engine*, illustrated in Fig. 1, Plate 77, has been developed from the atmospheric engine, which was the earliest form of pumping engine employed in mining operations. At the present time the best of the Cornish beam engines cut off the steam at about one-fifth of the stroke, but one-third or one-half is much more usual. In the early days of the Cornish engine expansion was carried to its utmost practical limit; but the risk incurred, and the numerous accidents met with in consequence, led to the adoption of a lower and safer degree of expansion, which caused a falling off in the duty obtained. The average duty of the reported engines in Cornwall thirty years ago was 67 millions, whereas it is now only 47 millions. In reference to the duty reports however, there are two serious defects that require correction. One is that the duty of the engine is not separated from that of the boiler; and the other is that the nominal and not the actual length of stroke is taken in calculating the distance passed over by the pump plunger. The actual length of stroke is variable, and generally falls somewhat short of the nominal length, because the enginemen as a rule work their engines with a considerable clearance from the spring beams, in order to avoid accidents. The remedy for this defect would be a continuous indicator, which would record the total distance passed over by the plunger.

An indicator diagram from a Cornish beam engine is shown in Fig. 38, Plate 92, and this is not merely a measure of power, but serves to show also how far the momentum imparted to the moving mass in the steam stroke has been sufficient to enable the steam to be used expansively and without wire-drawing. As the load to be lifted is a constant quantity throughout the stroke, the possibility of expanding the steam at all on the piston is due to the fact that the load is a mass of matter to which momentum can be imparted, and the expansive force of the steam can be utilised by changing the condition of the mass from a state of rest to a condition of quick motion, the momentum thus stored up in the mass being expended during the latter part of the stroke in maintaining the motion after the steam pressure on the piston has become less than sufficient to support the load. Thirty years ago the usual water load per sq. in. of steam piston area was from 12 to 16 lb.; but since that period it has been increased, and from 18 to 22 lb. is now in general use. The mean piston speed in feet per minute may be taken at 60 times the square root of the length of stroke in feet; and the proportionate time of the steam stroke to the equilibrium stroke is from five-sevenths to one-half, but as this is to a great extent under the control of the engineman there is not any definite rule.

The *Cornish Bull Engine*, illustrated in Fig. 2, Plate 77, is direct-acting, and is lighter than the beam engine by about the weight of the beam; the building required for it is smaller and less costly. The distribution of the steam is the same as in the beam engine.

The *Rotary Double-acting Beam Engine*, shown in Fig. 3, Plate 78, is much used in mining districts where stamps, crushers, and other machinery requiring rotary motion can be driven by the same engine; but it is not suitable for mining purposes where great pumping power is required, and it gives a lower duty than the Cornish engine. It has been much used however for water works and for sewage pumping. A suitable piston speed for this class of engine is found to be in feet per minute 80 times the square root of the length of stroke in feet, where the pumps are driven direct from the beam; but where there is a great length

of horizontal or vertical rods, and generally for mining purposes, the speed has to be limited to a much lower amount, such as 60 times the square root of the length of stroke, the same as in the Cornish engine. The effective power for a given size of cylinder is then double that of a Cornish engine; but as there is the addition of the flywheel and crankshaft &c., the cost of the two engines for the same power does not differ much.

In the engines already referred to, the speed of the steam piston is the same as that of the pumps, or very little greater; but in the *Horizontal Rotary Geared Engine*, illustrated in Fig. 4, Plate 78, the speed of the steam piston is much greater, being usually three or four times that of the pumps, so that the power developed per unit of piston area is generally three times greater than in the preceding classes of engine. The class of engine illustrated in Fig. 4 is much used for small works, where both pumping and winding can be conveniently done with the same engine; but for heavy pumping it is not suitable, in consequence of the wear and tear arising from the indirect application of the power, and from the backlash of the gearing. Experience has shown that the more direct the application of the power in pumping, the better is the result.

In Figs. 5 to 7, Plates 79 to 81, is shown the *Direct-acting Differential Pumping Engine* on the writer's design, in which a differential arrangement of valve gear is employed for effecting the distribution of the steam. The simplest form of this engine has a double-acting cylinder with the power applied direct to the pumps, the power per unit of piston area being the same as in the rotary beam engine, Fig. 3. The Compound Differential Engine shown in Fig. 5 has a pair of horizontal cylinders, the back end of the high-pressure cylinder A forming the front cover of the low-pressure cylinder B, as shown in the sectional plan, Fig. 6. There are two piston-rods to the low-pressure piston, which pass through tubes cast on the sides of the jacket of the high-pressure cylinder, as shown in Fig. 6; these two rods and that of the high-pressure cylinder between them are all fixed to

one crosshead, to which is attached the connecting-rod C for working the pumps D D, Fig. 5. The cylinders are bolted down upon a strong girder bed E; and the condenser F is carried on a separate bed behind the low-pressure cylinder B, the air-pump being worked by a tail rod from the low-pressure piston.

The differential valve-gear, which is the particular feature of the engine, is shown in Figs. 8 to 11, Plates 82 and 83, and its action is illustrated in the diagrams Figs. 12 to 15, Plate 84. These diagrams are not drawn to scale, but are intended to show clearly the action of the gear, whilst Figs. 8 to 11 show a practical example of its application to a compound engine. The main slide-valve G, Fig. 12, is actuated by the piston-rod through a lever H working on a fixed centre, which reduces the motion to the required extent and reverses its direction. The valve spindle is not coupled direct to this lever, but to an intermediate lever L, which is jointed to the first lever H at one end; the other end M is jointed to the piston-rod of a small subsidiary steam cylinder J, which has a motion independent of the engine cylinder, its slide-valve I being actuated by a third lever N, coupled at one end to the intermediate lever L and moving on a fixed centre P at the other end. The motion of the piston in the subsidiary cylinder J is controlled by a cataract cylinder K on the same piston-rod, by which the motion of this piston is made uniform throughout the stroke; and the regulating plug Q can be adjusted to give any desired time for the stroke.

The intermediate lever L, Plate 84, has not any fixed centre of motion, its outer end M being jointed to the piston-rod of the subsidiary cylinder J; and the main valve G consequently receives a differential motion compounded of the separate motions given to the two ends of the lever L. If this lever had a fixed centre of motion at the outer end M, the steam would be cut off in the engine cylinder at a constant point in each stroke, on the closing of the slide-valve by the motion derived from the engine piston-rod; but inasmuch as the centre of motion at the outer end M of the lever shifts in the opposite direction with the movement of the subsidiary piston J, the position of the cut-off point

is shifted, and depends upon the position of the subsidiary piston at the moment when the slide-valve closes. At the beginning of the engine stroke the subsidiary piston is moving in the same direction as the engine piston, as shown by the arrows in Fig. 12; and in the instance of a light load, as illustrated in Fig. 13, the engine piston having less resistance to encounter moves off at a higher speed, and sooner overtakes the subsidiary piston moving at a constant speed under the control of the cataract; the closing of the main valve G is consequently accelerated, causing an earlier cut-off. But with a heavy load, as in Fig. 14, the engine piston encountering greater resistance moves off more slowly, and the subsidiary piston has time consequently to advance further in its stroke before it is overtaken, thus retarding the closing of the main valve G and causing it to cut off later. At the end of the engine stroke, Fig. 15, the relative positions become reversed from Fig. 12, in readiness for the commencement of the return stroke.

These effects are further illustrated by actual indicator diagrams, Figs. 36 and 37, Plate 91, taken from a large differential compound engine employed for pumping at the Lambton Colliery in the county of Durham, having 27½ and 44 in. cylinders with 5 ft. stroke, and making 12 double strokes per min. These diagrams being taken during sinking operations, the engine was working at the time without the condenser, because the water was so full of mud that it could not be used to advantage for condensing. In this case there was a much heavier lift on one pumping quadrant than on the other; the cut-off was consequently at 47 per cent. of the stroke in the inward stroke, Fig. 36, and at 60 per cent. in the outward stroke, Fig. 37, the change at each successive stroke being made entirely by the automatic action of the differential valve-gear. The subsidiary piston J, Fig. 11, Plate 83, being made to move at a uniform velocity by means of the cataract K, the cut-off consequently takes place at the same point in each stroke, so long as the engine continues to work at a uniform speed; but if the speed of the engine becomes changed in consequence of a variation in the load,—if for instance the load

be reduced, causing the engine to make its stroke quicker, the subsidiary piston has not time to advance so far in its stroke before the cut-off takes place, and the cut-off is therefore effected sooner, as in Figs. 13 and 36. On the contrary, if the load be increased, causing the engine stroke to be slower, the additional time allows the subsidiary piston to advance further before the cut-off takes place, and the cut-off is consequently later, as in Figs. 14 and 37. This adjustment of the cut-off point in accordance with each variation in the load is entirely self-acting, and takes place instantly, however sudden or extensive the variation in the load on the engine may be; consequently the engine is rendered safe in working against variable loads, as it automatically and instantly varies the distribution of steam with every increase or decrease of the resistance. The action of the differential valve-gear is so sensitive and perfect that the load on the engine may be greatly varied whilst in full work, without requiring hand control by the stop-valve; engines on this plan may accordingly be employed to pump direct into town mains without the use of standpipes or balance valves.

The force acting on the subsidiary piston J, Fig. 11, Plate 83, is much greater than that required for moving the slide-valve, the excess being absorbed in driving the fluid in the cataract cylinder K through the small adjustable aperture Q; and as the resistance of the fluid increases as the square of the velocity, a very small variation only in the speed of the subsidiary piston can be effected by a considerable variation in the force upon it; so that the speed is maintained practically constant for a given adjustment of the cataract plug Q, although the boiler pressure of steam may vary. The main slide-valve G, Fig. 11, is opened at the beginning of each stroke by the motion of the subsidiary piston, which is controlled by the cataract; and a pause is consequently given at the completion of each single stroke of the engine, which allows time for the pump valves to fall to their seats. Slip in the water is by this means prevented, as well as the shock which occurs when pump valves close under the pressure from a moving plunger. This freedom from shocks in the pumps is an important point, giving safety from

accidents, such as the bursting of pipes; and at the same time the durability of the valves and seats is materially increased.

In Figs. 5 and 7, Plates 79 and 81, are shown the details of the arrangement for communicating the motion of the engine piston to the intermediate lever L of the valve-gear, Fig. 11, by means of the long lever H and connecting-rod R, Figs. 7 and 11, the lever H being itself actuated by a connecting-rod from the engine crosshead, as indicated in Fig. 5. An independent steam starting or pausing cylinder is provided at S, Fig. 7, the piston-rod of which carries a rack gearing into a pinion on one end of a tubular shaft T, Fig. 11; the other end of the shaft being made with a screw thread, its rotation traverses the outer end P of the lever N of the valve-gear, and thereby opens the small slide-valve I of the subsidiary cylinder J. The slide-valve of the pausing cylinder S is moved by tappets by means of the lever U, Fig. 5, which is actuated by the same lever H that works the inner end of the intermediate lever L of the valve-gear. The pausing cylinder S is itself also controlled by a cataract cylinder V on the same piston-rod, and the length of pause after each stroke of the engine is consequently determined jointly by the two cataracts V and K; the first regulates the time of opening the small slide-valve I for starting the subsidiary piston J; after which this piston, under the control of the other cataract K, has to travel a sufficient distance for opening the main slide-valve G of the engine. The adjustment of the cataract K also determines the mean piston-speed of the engine under the normal conditions of load and steam pressure.

In Fig. 8, Plate 82, is shown a longitudinal section through the steam-chests and slide-valves of the two cylinders; and Figs. 9 and 10 are transverse sections of the valves. The slide-valve G of the high-pressure cylinder has a couple of narrow ports through the thickness of the metal from end to end, as shown in Figs. 8 and 9, the effect of which is, that while the engine is pausing at the end of its stroke for the valve to be moved from mid position through the extent of the lap, a communication is established from one side of the piston to the other; so that, whatever the amount of clearance space left in front of the piston at the end of

the stroke, it becomes all filled with steam that has just done its work behind the piston. This prevents the slight loss that would occur in having to fill the whole clearance with full boiler steam at the commencement of the return stroke; the initial steam has now only to raise the pressure in the clearance from the terminal pressure in the high-pressure cylinder, instead of from the terminal pressure in the low-pressure cylinder. A double-beat valve W, Fig. 8, is provided in the steam pipe, and is worked off the main valve-spindle by means of a bell-crank lever and the pair of slotted connecting-rods X X; these are fitted with right-and-left-handed screws, so as to afford a ready means of adjusting the degree of expansion in the high-pressure cylinder under the normal conditions of the engine, without the use of a back cut-off slide; the main slide-valve G is also relieved from working under the full boiler pressure after the steam has been cut off by the double-beat valve W. The slide-valve Y of the low-pressure cylinder, Figs. 8 and 10, is balanced by means of a steel ring inserted in an annular groove Z on the back of the valve, as shown also in the plan, Fig. 11; this ring is pressed outwards against the steam-chest cover by an india-rubber packing ring compressed beneath it in the groove, and there are also a series of small holes in the bottom of the groove for the admission of the steam pressure behind the packing.

All the different classes of pumping engines admit of being made compound with more or less success; but the single-acting engine presents so many difficulties to this system, as almost to exclude its application. The advantages of compound rotary engines and their economy in fuel are now well established; but hitherto little has been done in the application of the compound system to non-rotary engines, although in principle it is so strikingly applicable to them. In the early days of the pumping engine, Hornblower, Trevithick, Woolf, and Sims all made attempts at compound non-rotary pumping engines, but without permanent success. Diagrams are given in Figs. 33 to 35, Plate 90, of Trevithick's and Sims' compound engines, and the Haerlem Lake compound Cornish engine; and in Fig. 6, Plate 80, is shown the compound differential

engine already described; the mode of distributing the steam is indicated by the arrows in each diagram.

The ratio of expansion that can practically be employed in a single-cylinder non-rotary engine is very limited, and is dependent upon the amount of momentum that can be stored up in the moving mass. In the indicator diagram, Fig. 38, Plate 92, the work due to the darker shaded area above the line of mean pressure is stored up in the moving mass during the first part of the stroke, and given out again during the latter part; and the amount of this work is proportionate to the weight in motion multiplied by the square of its velocity. In order to expand to a great extent in a single-cylinder, there must be a great variation between the initial and the terminal pressure, requiring a large amount of momentum to be imparted to the moving mass in the first part of the stroke; and consequently, in order to make up this amount, if the weight were small the velocity would have to be very great. But as the piston speed is practically limited to a moderate velocity, it is necessary for the mass to be very great, in order to admit of a high ratio of expansion; and accordingly Cornish engines often have to put in motion a much greater weight than that necessary for lifting the column of water in the pumps, otherwise they could only realise a moderate degree of expansion. It is for overcoming this difficulty that the second cylinder of the compound engine is so advantageous; and the compound system becomes a necessity for carrying expansion beyond the moderate limit practicable in a single cylinder.

In the indicator diagram, Fig. 39, Plate 92, taken from a compound rotary engine, the ratio of final expansion is 10 to 1, but the variation between the initial and terminal pressures in either cylinder is less than $2\frac{1}{2}$ to 1, instead of a variation of 10 to 1, which would have been the case with a single cylinder. In other words, the variation in a single-cylinder engine cutting off at 40 per cent. of the stroke is greater, and consequently necessitates a greater momentum in the moving mass, than in the case of a compound engine expanding as much as ten times. This

enables the compound engine to be applied direct to pump plungers without the intervention of heavy attachments.

It will be observed that the variation of pressure in the examples of indicator diagrams from compound engines, shown in Figs. 36, 37, and 39, Plates 91 and 92, is not so great as the theoretical amount. These are not exceptional cases; but the difference arises from the following cause, which applies generally. On the admission of the steam from the high-pressure to the low-pressure cylinder a considerable condensation takes place, which lowers the initial pressure in the second cylinder, and consequently reduces the extent of variation in pressure. This however does not represent a loss as compared with the single-cylinder engine, for in the latter case the same condensation takes place in the initial steam entering the cylinder, although it cannot be shown by the indicator diagram, because it occurs while the cylinder is being supplied from the boiler.

Pumps and Pitwork.—In pumping from great depths the arrangement of the pumps and pitwork requires special consideration. The Cornish system is illustrated in Fig. 17, Plate 86. The action of the engine in this case is such that the security of the pitwork depends particularly upon the complete charging of the pumps with water during the steam or suction stroke; because at the end of that stroke, if the pumps are not charged solid, the weight of the pump spears carries the plungers back with a great shock. As the steam stroke is performed very quickly, a considerable water-way through the suction valves is requisite; and for further security it is usual to have very short suction pipes. In many cases for heavy pitwork a small head of water on the suction side is also provided, and duplicate suction valves are employed. With the Cornish engine it is necessary to have a constant load to lift, and the occurrence of any variation in the pressure or load, such as a quick rise in the boiler pressure or an accidental failure of the drawing lift, may cause the breakage of the spring beams. For waterworks, in the cases where the

water load is not constant, a balance valve is often put on the water main to preserve a constant load on the engine; and as a further means of control a throttle-valve is often put in the equilibrium pipe of the engine. But these contrivances only adapt the engine to a variable load, whilst the work actually done by the steam has to be always equal to the maximum water load, however much the real load at any time may be varied.

Another system of pitwork, the Bucket Lift shown in Fig. 18, Plate 86, with the Butterfly Valve shown in Fig. 32, Plate 89, is generally used for sinking purposes; and in many colliery districts this is the most common for permanent lifts. The spear rods are in this case much lighter than those required for plunger pumps, —unless the plungers are inverted, as in the Inverted Ram Pump, Figs. 19 and 20;—and the occurrence of air getting into the pumps does not cause the shock that is experienced with plungers. This is however an expensive system in maintenance, because of the necessity for constantly changing the buckets.

To obviate this difficulty and combine the good qualities of the plunger and of the bucket system, the Hollow Ram Pump shown in Fig. 21, Plate 87, has been successfully used. It consists of a hollow plunger A, having on the top end a valve B, Figs. 22 and 23, which is closed during the upstroke, Fig. 22, and opens in the downstroke by rising up against the stop C, Fig. 21. The plunger works through an internal stuffing-box in the rising column D; or the stuffing-box can be placed outside, so as to afford means of tightening up without stopping the engine and emptying the column.

All the systems of pump lifts worked by means of spear rods are very expensive to maintain, and have the objections of occupying great space in the shaft and involving great expenditure in construction. These evils have been so severely felt that the plan illustrated in Fig. 16, Plate 85, is now becoming very largely adopted, the spear rods, beams, and quadrants being here entirely dispensed with, by placing the engine underground at A, and employing it to force the water to the surface direct. A number

of such engines have recently been put down by the author's firm, and they are now engaged on some of very large size, one of which is 200 H. P. and is for the Navigation Colliery in South Wales, where it is to force the water 1100 ft. high in one direct lift. When the pumping engine can be placed near the water level, without risk of the water rising during a temporary stoppage so as to drown the engine, this is certainly the best plan on every consideration, and effects a very large saving in the cost of maintenance. If the engine cannot be placed within suction reach of the water without danger, it can be placed at some short distance, say 50 ft. up the pit, and the water can be lifted to it by means of a common lift or quadrant, or by a hydraulic engine, as shown at B in Fig. 16, Plate 85, the full head of water in the rising main C being employed for working the hydraulic engine through the pipe D. On this plan all the pumping may be done in the winding pit. A certain amount of condensation is of course incurred by taking the steam down the pit from boilers at the surface; but this loss is very trifling compared with the saving effected in the application of the power, and by well clothing the pipes the condensation is reduced to a small amount.

Pumps and Valves.—In pumping under such heavy pressures, special attention has to be given to the construction of the pumps and valves. The double-acting plunger pump shown in Figs. 24 and 25, Plate 88, has been much used by the author for this purpose, and he has found this and the ordinary single-acting plunger pump, Fig. 26, to be the best in working. The double-acting piston pump shown in Figs. 27 and 28, is for smaller quantities of water and lower lifts.

The single-beat or mitre valve shown in Fig. 29, Plate 89, answers well for pumps of moderate capacity, when provided with india-rubber springs, as shown at A A; but for large pumps no valve is found to answer better than the double-beat valve, shown in Fig. 31. Disc valves of india-rubber, as shown in Fig. 30, are durable for moderate pressures below 50 lb. per sq. in.

A pair of the differential pumping engines with 20 in. cylinders have been working for nine months in the Morton Pit at Clay Cross Colliery near Chesterfield, with a direct lift of 950 ft.; and they are stated by the Engineer, Mr. Howe, to keep at work satisfactorily, and to run perfectly steady up to 18 double strokes per min., of 3 ft. length, without any shock being perceptible. The steam is conveyed down the pit by a pipe $7\frac{1}{2}$ in. bore and 1100 ft. total length, which stands upon a timber bed at the pit bottom, and is stayed at every 27 ft. length. There is a single expansion joint near the top, and the total expansion from the heat of the steam is 18 in., amounting to nearly 2 in. per 100 ft. length. The whole length of pipe is clothed with non-conducting cement, and the steam is delivered into a receiver at the pit bottom, 3 ft. diameter and 6 ft. length, in which the water formed by condensation is deposited. The loss of steam from condensation has been ascertained by direct measurement of the water deposited in this receiver, and is found to amount to 8 cub. ft. of water per hour when the engines are standing, and 12 cub. ft. per hour when working at the ordinary speed of 10 double strokes per min., with 45 lb. steam. Taking the evaporative duty of the coal at 9 lb. of coal per cub. ft. of water, the loss of coal from this condensation in the steam pipe amounts to 72 lb. per hour when the engines are standing, and 108 lb. per hour when working; and the loss per 24 hours would therefore be 2160 lb. if the engines are standing half the time, or 2592 lb. if working continuously.

Although the two engines are in no way connected together, after a little adjustment of the stop-valves they work continuously at right angles relatively to each other of their own accord, as truly as if coupled to right-angled cranks on the same crankshaft; and this is also the case in other similar instances, the reason being that in the right-angled position the least resistance is encountered by the engines, because the variation in the velocity of the water column is then a minimum.

Mr. Davey exhibited models of the compound differential pumping engine; and a working model illustrating the action of the differential valve gear, and showing how the main slide-valve derived its motion from a lever, one end of which was worked by the engine piston, while the other end had an independent motion from a subsidiary piston controlled by a cataract. In starting the engine, steam was first admitted to the cylinder of the subsidiary piston, which moved forwards with a steady uniform pace at the speed allowed by the cataract, and thereby opened the main slide-valve, the engine end of the valve-lever being for the moment at rest. The engine then commenced its motion; and if the load upon it were small in proportion to the pressure of steam on the piston, it would move off with a comparatively high velocity, and would thus more quickly overtake and neutralise the lead which the subsidiary piston had had over it, thereby cutting off the steam at an early point of the stroke. But on the other hand, if the resistance were great, compared with the steam pressure, then the engine would move off more sluggishly and would be longer in overtaking and neutralising the lead of the subsidiary piston; so that the cut-off in that case would take place much later than in the former instance. If, instead of being simultaneous, the two movements imparted to the valve-lever had been made to take place in succession, the subsidiary piston having the lead, the main slide-valve would always have been opened to the full extent at the commencement of the engine stroke, and would always have been closed at exactly the same point in that stroke, and there would consequently have been no variation in the cut-off to suit different loads. But as the two movements were simultaneous, the travel of the valve gear was a continuous gliding motion, differentially compounded of the two movements, the one given by the independent subsidiary piston being a uniform movement, while the other being dependent upon the motion of the engine was a variable one. So long as the motion of the engine continued constant, the relative movements of the engine-piston and slide-valve would be constant also; but

whenever the motion of the engine varied, these relative movements and the consequent point of cut-off would vary correspondingly.

Mr. W. Menelaus enquired how it was proposed with this plan of direct-acting pumping engine to deal with the water while sinking pits. Perhaps this plan of engine would be the best in the end, after the pits had been sunk; but the ordinary Cornish engine had the advantage of enabling the sinking to be done with it, and of being then available for permanent pumping after the pits were down to their full depth. He wished to know whether it was proposed to introduce this direct-acting engine at the outset for getting rid of the water in sinking, or how the pumping was intended to be done during that operation.

Mr. Davey said that for sinking a pit at the Lambton Colliery, Durham, he had lately put down a 200 H.P. pumping engine on the horizontal arrangement shown in Plate 79, connected by quadrants to ordinary pump rods; and having finished one pit, it was now employed in sinking a second, on the completion of which the engine would be placed underground, as in Plate 85, and applied direct to the pump, by simply bolting the latter upon the engine bed and attaching the pump plunger to the engine crosshead, and so employing the pump to force the water to the surface. There were many difficulties in pumping whilst sinking a pit, which were entirely got over by the compound differential engine. One difficulty was that of "working on air," as it was termed; and a still greater one was that of a "riding column," when a chip or other obstruction happened to get under the bottom clack of the drawing lift, for instance, and the whole weight of the column of water was consequently thrown on the engine in the return stroke. At the Lambton Colliery with the engine working a pair of quadrants, as in Plate 79, a sinking lift was attached to the first quadrant to carry the pit down 50 fathoms, and then a second lift was put on the other quadrant to reach another 50 fathoms. But when 45 fathoms had been sunk with the first lift, and it was not yet balanced by the second lift on the

other quadrant, the bottom clack failed, and the whole 45 fathoms of the 18 inch column was then riding on the bucket. There were no catch pieces whatever to the engine, except the cylinder covers; but the engine continued working with this riding column without any injury whatever. In that case the total weight on the engine in the outward stroke was as much as 7 or 8 tons; and in order to save the cylinder covers from being carried away, steam had to be admitted on the opposite side of the piston, reversing the ordinary working of the engine and forming a cushion in front of the piston; and this was entirely accomplished by the automatic action of the differential valve gear. Other engines of the same description had since been put up for sinking purposes with the same result; and he had seen one of them recently working for half an hour with the bottom clack gagged and the whole column on the engine.

Mr. W. Menelaus said he fully admitted the advantage of the direct-acting pumping engine now described over the Cornish engine in the cases mentioned, as there was certainly less danger in working by that system than by the Cornish; but for dealing with the water in sinking he wished to know whether any special machinery was required, which would be thrown away after the pit had been sunk. On shifting the pumping engine to the bottom of the pit after sinking, the spears and pitwork that had been used during the sinking would of course be done away with.

Mr. Davey replied that a certain portion of the pumping gear used in sinking would have to be discontinued when the engine was placed underground on the completion of the sinking, and would be thrown away as far as regarded the particular work for which it had been employed; but it would serve again for a similar purpose elsewhere.

Mr. W. Menelaus feared that in deep pits, on account of the very great cost of putting up temporary machinery for pumping while sinking, the Cornish engine would be found preferable to the direct-acting engine now described, notwithstanding certain

advantages attending the latter. If this plan had furnished the means of getting rid of the water in sinking, without afterwards throwing away the spears and a great deal of the pump work that had been used temporarily in sinking the pits, then there would be but little question as to its merits for moderate depths in comparison with the Cornish plan. The engines that were being made on the new plan for pits in the South Wales district were for collieries where the sinking was already completed. But in taking account of the very heavy cost of temporary pumping machinery for keeping the water down while sinking the pit, he feared it would be found that upon the whole the Cornish engine was the cheapest. He fully recognised the very ingenious way in which the difficulties encountered in pumping from mines had been met by the excellent arrangements described in the paper, and the remarkable step that had been taken in working direct against a column of water of 1100 feet height, as compared with the ordinary Cornish engines working against a column subdivided into heights of about 300 feet.

Mr. E. B. Marten asked by what means a cushion of steam was admitted in front of the piston to check it in the outward stroke whenever anything happened to prevent the pump valves from closing properly.

Mr. F. F. Ommanney enquired what description of pump valves was found the best, especially with reference to the speed of the water through the valves.

Mr. C. Markham considered that as a rule the pumping machinery used for sinking had better be thrown away on the completion of the sinking operation, or at all events it should be removed and adapted to some other purpose. He agreed in thinking that there was no pumping engine which worked so well as the Cornish; he had himself constructed several of them lately, and had the greatest confidence in the system. He believed however that the principle of pumping by direct action and with

variable expansion, as described in the paper, was really a very valuable improvement: the first pump of that sort had been designed and fixed for him at Staveley by Mr. Davey about two years ago in substitution for a double-acting piston pump, and had worked extremely well and continuously from the time of starting; it was situated underground and was pumping under a heavy column of about 700 feet head. The use of plunger pumps appeared to him to possess many advantages in comparison with piston pumps; for in the old plan of working under a heavy pressure with a piston, if dirty water were met with, the pump would never give satisfaction: the cylinder got worn away very rapidly, and the water slipped by, so that the pumping became very defective and a costly operation. At the same time he did not like carrying steam down a pit to an underground engine, if it were possible to have the work done at the top.

Mr. E. A. Cowper, referring to the differential valve motion described in the paper, observed that he understood the principle to be that the valve-rod was attached to the middle of a lever, one end of which was connected to the engine crosshead so that it moved at the same time as the piston, though with less stroke; while the other end, instead of being mounted on a fixed fulcrum, was in this arrangement moved by a small steam cylinder controlled by a cataract, by which it was regulated to a uniform speed of motion, as slow as might be desired. If the engine had very little work on it, the piston would start away very quickly, faster than the cataract, and shut off its own steam; but if it had a heavy load, it would start off less quickly, and would take more steam before cutting off. The cataract was the measurer of time, and it was the small steam cylinder with the cataract which gave motion to the one end of the valve lever.

He agreed in considering that for many purposes, such as pumping and blowing engines, it was desirable not to have any great expansion in one cylinder. Although a high expansion might be practicable in one cylinder where there was a great weight of pump rods, balance bobs, &c., as in some of the Cornish engines, yet in ordinary

waterworks pumping engines, blowing engines, and good factory and marine engines, where there was no great load of that description, expansion could not be carried far in one cylinder. Therefore the compound principle of having either two cylinders to one beam, or two cylinders in two separate engines, was undoubtedly the best way of getting large expansion: all the more economical engines were now compounded in one way or other.

With regard to the spears used in sinking a pit being thrown away when the sinking was completed and when the engine was shifted underground to pump from below, there was no want of economy in not using that which was not wanted and which yielded no profit; the spears would simply be laid aside, and if they could be employed again on some other occasion, so much the better, but there was no use in working them unnecessarily. What the author of the paper did was simply to move the engine to the bottom of the pit when sunk, in order thereby to work it more economically and more safely than could be done with a Cornish engine; he believed it was certainly the case that the engine could be worked more safely in that way, and that on the whole there was also a saving of cost by the plan.

The particulars furnished in the paper with regard to the condensation of steam in pipes were confirmed by some experiments made for him by Mr. Walter May in Birmingham, with a length of 8 feet of steam pipe clothed with haybands, and outside the covering of haybands there was a covering of zinc. The pipe was of cast iron, 3 in. inside and $3\frac{3}{4}$ in. outside diameter, and $6\frac{3}{4}$ in. outside the covering. The condensation depended upon the completeness of the clothing, being rather less where the clothing was well done, and rather greater where it was not quite so good. There was 40 lb. steam pressure in the pipe; the temperature of the air was 75° Fahr. The condensation per hour in the pipe was found to be an average of 0·125 lb. of water per sq. ft. of the outside surface of the covering, or 0·219 lb. per sq. ft. of the outside surface of the pipe. The experiment described in the paper was a particularly valuable one, having been made on so great a length as 1100 ft. of pipes of $7\frac{1}{2}$ in. bore.

Mr. Jeremiah Head said he had experimented with a stack boiler attached to a puddling furnace, with a view to ascertain its greater evaporative efficiency when covered with a non-conducting material than when quite unprotected. The evaporation was recorded by a Siemens water meter inserted in the feed pipe, and the observations extended in each case over eleven shifts, or one week working night and day. The average temperature of the external air was 60° Fahr., and that of the steam and water in the boiler was 300°, corresponding to a pressure of 52 lb. per sq. in. above the atmosphere; the temperature of the feed water was 162° in each case. The boiler was 22 ft. 6 in. high and 4 ft. 2 in. diameter, and the extent of surface covered was 242 sq. ft., the thickness of the covering being $1\frac{1}{2}$ in.; the non-conducting material used was of a carbonaceous character, manufactured at Middlesbrough. The average rate of evaporation from 162° was 14·8 cub. ft. per hour when the boiler was uncovered, and 20·4 cub. ft. per hour when covered. Allowing for the difference between the temperature of the feed water and that of boiling water, 5·9 cub. ft. per hour would be the equivalent loss of boiling water at atmospheric pressure in the uncovered boiler, or 352·8 lb. per hour; and this being divided by 242 sq. ft. of uncovered surface gave 1·46 lb. per hour as the weight of steam condensed to water of 212° temperature per sq. ft. of exposed surface. It might accordingly be taken approximately that three such boilers properly covered were as efficient as four not covered.

Mr. C. Markham enquired whether in the experiment described in the paper the pipes conveying steam down the pit were exposed to a current of air or not.

Mr. Davey replied that the steam pipes were in the downcast pit in a strong current of cold air.

With reference to the remarks which had been made respecting the use of the horizontal pumping engine after the sinking of a pit had been completed, it was to be observed that, if there were any objection in any particular case to putting the engine underground

after it had been employed in sinking, it might remain at the surface where it was originally fixed for sinking, and there would be no difficulty in working it in that position as a permanent engine under the same conditions as those in accordance with which the Cornish engines were worked.

In regard to the speed of the water through the pump valves, he had not made any experiments upon this subject, but had usually provided such an area of water-way as would give a speed of from 200 to 250 ft. per min. through the valves, and he had found this to work well in practice; how far it accorded with the experience of others he did not know.

The contingency of the drowning of the engine when placed underground was provided against by the arrangement shown in Plate 85; this consisted in placing the engine at a safe distance above the bottom of the mine, and putting a hydraulic engine below at the bottom, which would raise the water to the pumping engine, and would continue to work even when entirely submerged. At the present time in a colliery in Westphalia he was fixing a pair of pumping engines 900 ft. below ground, to pump the water to the surface. The principal parts of the workings were below the level of the engines by as much as 250 ft.; and in order to raise the water to the main engines and still keep them in such a position that the whole of the workings might be flooded without drowning them, a pair of hydraulic pumping engines were provided, placed at the bottom, with starting valves in the main engine room, so that the hydraulic engines could be set to work from the main engine room although the whole of the lower part of the pit might be filled with water. As a further security a staple might be put down from the main engine room to the hydraulic engines (tubbed or otherwise made water-tight) with a ladder of access, so that in the event of a flood in the workings the hydraulic engines would still be in the dry, and accessible for repairs.

As regarded the action of the differential valve gear in making the engine safe for working with a riding column of water or with a broken spear, it would be seen from the diagrams of the valve

motion that, whenever the proportionate speed of the engine end of the valve-lever exceeded that of the cataract end, the action of the slide-valve would be reversed from its ordinary mode of working, and it would admit steam on the opposite side of the piston. If therefore the engine started off with a very quick speed, as it would do in running away with the weight of a hanging column of water, the steam would thereby be admitted in front of the piston to oppose its motion, and would form a cushion bringing the piston to rest before reaching the end of the cylinder.

From the results given in the paper of the experiments at Clay Cross upon condensation in steam pipes, it appeared that when the engines were working the loss of fuel from condensation in the 1100 ft. length of $7\frac{1}{2}$ in. pipes was 108 lb. of coal per hour; and as a $7\frac{1}{2}$ in. pipe would supply a 108 H.P. engine working with little expansion, and within moderate limits the condensation was not practically affected by the velocity of the steam in the pipes, he had concluded that, for a single-cylinder engine working non-expansively and developing 100 H. P., the condensation of steam in the pipes of 1100 ft. length and $7\frac{1}{2}$ in. diameter would be found to be equivalent to about 1 lb. of coal per Ind. H. P. per hour. But if a compound engine were being supplied from the same pipes, instead of a non-expansive engine, the power developed by the same quantity of steam would be more than doubled; so that for a compound engine working underground, 1100 ft. below the surface, and having the steam carried down to it, the loss by condensation would be about $\frac{1}{2}$ lb. of coal per Ind. H. P. per hour, being only a small percentage of loss, and probably less than that occasioned by the friction of the massive spear rods and buckets of an ordinary Cornish pumping engine.

The PRESIDENT observed that the very interesting paper which had been read included not only what might be called a novel system of pumping; but also a most ingenious mode of regulating the motion of the slide-valve, by coupling up a regularly moving piston governed by a cataract, with one which might be irregularly moving, namely the piston of the engine itself. The valve-lever

deriving its motion at one end from the cataract and at the other end from the engine piston, the slide-valve connected to an intermediate point partook of the resultant of those two motions, and in that way the eccentricities of speed of the engine piston were kept in check by the steady-going cataract. He had been struck very much by the ingenuity with which this plan of valve motion had been worked out so completely that, in the case of extreme speed of the engine piston, the action really amounted to a reversal of the steam, and in that way accident seemed to be rendered almost impossible.

He proposed a vote of thanks to Mr. Davey for his paper, which was passed.

The following paper, communicated through the President, was then read:—

ON THE HELICAL PUMP.

By Mr. JOHN IMRAY, of London.

During an experimental enquiry relating to turbines, made by Mr. Matthew Boulton and the writer in 1867, their attention was particularly directed to the application of such instruments in an inverse manner; that is to say, instead of employing them for the purpose of obtaining rotary motion from a stream of fluid, driving them by power for the purpose of creating a fluid current. One of the models experimented on for this purpose consisted of a plain paddle wheel, revolving within a cylindrical casing prolonged beyond the wheel on each side, and provided with fixed guides in the prolonged ends, like those of a parallel-flow turbine. These guides were curved, starting at their outer edges in the direction of the axis of the cylinder and bending nearly at right angles, their inner edges terminating at an acute angle with the side of the wheel or plane of revolution. When the wheel was caused to revolve, water was drawn in at one end of the cylinder, and was deflected by the entering guides so as to form a series of helical currents slightly inclined to the plane of revolution of the wheel; these currents were carried round by the wheel blades, and delivered into the passages of the issuing guides, where they were again deflected into the direction of the axis of the cylinder. In this model, owing to the curvature of the guides, the area of passage through them gradually diminished on the one side of the wheel, and gradually increased on the other side; the one set of passages, those of supply, thus resembled the vena contracta, wherein a fluid current acquires velocity by losing pressure; and the other set of passages, those of discharge, resembled the expanding outlet or cone of Venturi, wherein a fluid current acquires pressure by losing velocity.

The instrument being symmetrical in form was reversible, that is to say, the direction of the current produced by it was reversed by reversing the direction of rotation of the wheel.

The results obtained with this model were such as to encourage further enquiry in a like direction, and the idea illustrated by the diagram, Fig. 5, Plate 94, readily suggested itself. It was thought that if it were possible to cause a series of blades B B to move through a liquid contained in a canal C C in a direction as nearly as possible coincident with that of the canal, a current would be set up and maintained in the liquid at a velocity very nearly equal to that of the blades. Obviously this arrangement in a straight canal is impossible, because in that case the series of blades would have to be infinitely extended, and there would be no means of closing the liquid in at the points where the successive blades enter and leave the canal. It seemed possible however to apply this principle, by arranging the blades and bending the canal round the circumference of a circle, in which case the canal being inclined to the plane of revolution of the blades would necessarily be of helical form.

On this idea the first model of the Helical Pump was constructed; and it may be noticed that the proportions adopted in that model have, after experience during several years with pumps of various dimensions, been found to be practically as good as any that can be used for the purpose. The construction and action of the helical pump may be illustrated by imagining that a large shallow nut is tapped with a screw thread making only two complete turns in the length of the nut, the space between the threads being about eight times the thickness of the thread, as shown in the diagram, Fig. 6, Plate 94; and then that the helical groove or channel is extended tangentially outwards at each end of the nut. A cylindrical recess is then turned out of the interior of the nut in the centre, to the same depth as the thread, cutting away one entire turn of the thread, and leaving a portion of the thread on each side of it, as shown by the dotted rectangle in Fig. 6; and into this space is introduced a simple paddle wheel, with a boss on each side filling up the aperture of the nut. This combination then accurately represents the helical pump; the thread of the nut

forms a channel of square section, with a tangential inlet on the one side of the nut and a tangential outlet on the other side, the body of the channel being carried helically round, so as to present an oblique opening on each side of the wheel to the spaces between the blades. The channel being charged with water and the wheel being caused to revolve, the water caught between the blades is carried round with them, and gradually shunted across their width by the inclination of the helical sides between which it revolves: as illustrated in Fig. 5, which may be taken as a developed view of a portion of the circumference of the wheel, and of the helical passage to and from the wheel. The water thus carried round and shunted across the wheel becomes a current, entering by the one tangential passage and issuing by the other, with a velocity nearly equal to that of the wheel blades. The wheel in fact is made to resemble in its action the barrel of a capstan or windlass, winding a rope upon it tangentially, and paying off an equal length: the turns of the rope (which in the case of the pump is a liquid one) being made to slide their own breadth along the barrel at every turn.

The ordinary construction of the Helical Pump is shown in Fig. 1, Plate 93, which is a front view or longitudinal section of the wheel and one half of the casing, the front half being supposed to be removed; Fig. 2 is a plan of the whole pump, and Fig. 3, Plate 94, a transverse section; Fig. 4 is an edge view of the wheel. The casing is made in two precisely equal and similar halves, both to the same hand and cast off the same pattern, bolted together and enclosing the wheel between them. Each half of the casing has a tangential passage A, one of which serves for inlet and the other for outlet, the direction of current being determined by the direction in which the wheel is made to revolve; the canal, beginning from the inlet passage and terminating with the outlet, is carried round two complete screw turns, the helical partition which would separate the one turn from the other being omitted to give room for the wheel. It will readily be seen that the workmanship necessary to fit up such a pump is of the simplest and cheapest

character. The casings have only to be bored out in the centre to provide bearings for the shaft, and faced on the flanges to make a tight joint when they are bolted together; and for the wheel it is only necessary to bore out the boss and key it on the shaft. The bosses of the pump casing in which the shaft works require no glands, because owing to the centrifugal action there is always a suck in. Practically these bearings are lubricated with melted grease, which is drawn in very freely while the wheel revolves, and which, setting when the pump stops, effectually seals the bearings against leakage.

From theoretical considerations it appears that a pump of this kind should present some important advantages as compared with many rotary pumps. In the first place the channel for the liquid is free from sudden bends; it is a simple circular sweep from the tangential inlet to the tangential outlet, presenting little more frictional resistance than a straight pipe of equivalent length. But in many rotary pumps there are numerous bends, some of them of rather abrupt character: for example, the supply pipe is often made to fork into two branches, which have to be bent at right angles to deliver into the central space of the pump; and from this central space the water which enters parallel to the axis has to be bent again at right angles so as to stream outwards into the plane of revolution. Also at the periphery of the pump the water has again to bend from its radial direction into the circular sweep of the volute pipe, which leads it to the tangential outlet. In the helical pump all these bends are avoided, except the one circular sweep round the circumference.

Again, in many rotary pumps the liquid current has to undergo great changes of form: for example, the water enters the central space in the form of a cylinder, which has to spread out into a sheet of disc form, gradually thinning down till it issues from the narrow slit on the edge of the wheel, to be again collected into a tapering stream in the outer volute. These changes of form and also of sectional area of stream are necessarily accompanied by variations of velocity and pressure, involving fluid friction. In the helical pump, on the other hand, the passage from inlet to outlet undergoes

no change of form or area, the velocity of the current and the pressure remain the same throughout, and it may therefore be concluded that the fluid friction is reduced to a minimum. But this reduction of fluid friction is not the only advantage resulting from the constancy of form and area in the channel. This uniformity of passage, in conjunction with the ease of the curvature, renders the helical pump peculiarly applicable for raising or forcing liquids in which solid matters are suspended, as for example, sewage water. A solid body having once entered the inlet finds no obstruction to its progress through the pump till it is discharged at the outlet.

For the purpose of testing the efficiency of the helical pump, experiments were first tried with a model having a wheel only 3 in. diameter and a channel $\frac{1}{2}$ in. square, as with this size there was no difficulty in applying actual measurement to the discharged water, and comparing the quantity with that which was due to the velocity of the wheel, and which should be discharged if there were no loss of efficiency. With a pump of large size, having a wheel 3 ft. diameter, and a channel 6 in. square, the measurement of the discharge was attended with considerable difficulty, owing to its great volume and the want of convenient tanks to hold the supply and discharge. These difficulties were however overcome by measuring, not the whole discharge, but a known fraction of it, in the following manner: the discharge pipe from the pump was made to deliver into the higher end of an inclined trough or spout, which gradually widened out towards its lower end to a width of 50 in. Several intercepting weirs and bridges were placed across the trough, so as to distribute the current uniformly over its width, and to produce at the lower end of the trough a cascade of nearly uniform depth and velocity. A portion of this cascade was intercepted by a spout 1 in. wide placed below it, and while the main body of the cascade was allowed to flow back into the tank whence the pump drew its supply, the fraction of the discharge intercepted by the narrow spout was led into a separate vessel to be measured. As the whole width of the cascade was 50 in., and the width of the intercepting spout

was 1 in., it was assumed that the measured water represented one-fiftieth part of the whole discharge. As the cascade might not throughout its width be absolutely uniform in depth and velocity, any error arising from this cause was eliminated by traversing the spout slowly from side to side during the experiments, so as to intercept successive portions of the cascade at all different points in its width, and thus to obtain a fair average of the whole.

The results of the experiments with the model and with the full-sized pump were singularly alike, and were as follows. Taking the velocity of the blades of the wheel as that of their middle points (the mean between the greater velocity at the tip and the less velocity at the root of the blade), and multiplying this velocity by the area of the blade or of the pump channel, a volume was obtained which would represent perfect efficiency or total absence of slip. The actual efficiency, found by trial at many different altitudes of discharge from 3 in. up to 12 ft. above the level of supply, varied from 82 to 85 per cent. of the complete efficiency, showing that there was a slip of the blades amounting to from 15 to 18 per cent. of their mean velocity. With such pumps it is always possible to apply great power without obtaining any efficiency whatever, for the wheel may be driven at such a speed as merely to balance the column in the discharge pipe without delivering any water, the same water being then kept in continuous rotation between the blades of the wheel, and none of the water shunted across from one side to the other. In such cases the height at which the water was kept in balance was always found to be accurately double the height due to the velocity, or the height in feet was 1-32nd of the square of the velocity in ft. per sec. For example, when the mean velocity of the blades was 16 ft. per sec., the height of column supported without discharge was 1-32nd of $(16)^2$ or 8 ft. This result is consistent with the theoretical consideration of the subject. When, for instance, water issues from an orifice under a head of 4 ft., the velocity of the issuing stream is 8 times the square root of the height, being $8\sqrt{4}$ or 16 ft. per sec. If this stream be made to play on a hollow surface, or on a surface bounded at the sides in such a manner that

the water cannot escape laterally, but must be reflected entirely backwards, the pressure on the surface is twice that due to the velocity, or in the case under consideration is the same as that of a head twice 4 ft., that is to say 8 ft. high. Conversely, when a blade is moved against water with a velocity of 16 ft. per sec., the water being confined so that it cannot escape laterally, as in the case of the helical pump, the pressure on the blade is equivalent to a head of 8 ft., and consequently a succession of blades striking the water support a column of 8 ft., or double the height due to their velocity. In such a case the efficiency is nil, because there is no discharge, but only equilibrium. If however, the velocity of the blades remaining the same, the head pipe be opened at half its height, the best conditions for efficiency are presented; and in such cases the efficiency of the helical pump was found to vary from 82 to 85 per cent., as already stated.

As it appeared from these results that the velocity of the water was less than that of the blades, it was thought advisable to set the blades at a little backward inclination to the axis of the wheel, so that the water in meeting them should glide gently along them without receiving the blow due to the difference of velocity. This alteration however did not seem to be of any benefit, but rather the reverse, as there was an end pressure on the shaft which did not exist when the blades were parallel to the axis. The blades now usually employed are bent a little forwards at the entering edge, and backwards at the leaving edge, as shown at D D in Fig. 4, Plate 94, rather for the purpose of stiffening them by the corrugation than for accommodating them to the flow of the water.

Some experiments were made with the helical pump with a view to ascertain by the indicator the efficiency of the pump in respect to the power expended in working it. The result of these gave as the work done 58 per cent. of the power applied, 42 per cent. of the driving power being lost in friction or otherwise. When the engine and pump were worked without water at the same speed, the friction was found to be about 14 per cent. of the total power which had been applied to pumping. As this was the friction while

no work was done, and consequently while there was little strain on the moving parts, it might probably not be incorrect to assume that the total friction of the engine and pump while doing work must have been nearly double, or at least 25 per cent. of the total power developed; adding this estimate to the 58 per cent. of actual efficiency observed, the total 83 per cent. corresponds very nearly with the efficiency observed when speed only, without regard to power, was taken into account.

These results may be thus summarised:—assuming that the pump has such an area of passage and is driven at such velocity that it should, if there were no loss, deliver 100 gall., then it will actually discharge 82 to 85 gall., giving a slip equivalent to from 15 to 18 gall. Assuming that 100 ft.-lbs. are applied to drive the pump, then the actual work performed by it, that is to say the weight of water multiplied by the height to which it is raised, will amount to about 58 ft.-lbs., the friction of the engine and pump being about 25 ft.-lbs., and the loss by slip being, as already stated, about 17 ft.-lbs.

In conclusion, it may be observed that, though it is several years since the helical pump was brought out, it has not until lately come largely into use: the manufacture not having been actively carried out until it was taken up by Messrs. Brotherhood and Hardingham, to whose energy, and particularly to their ingenuity and skill in applying to the pumps their elegant triple-cylinder engine, is due in great measure the success which now attends the helical pump. There are now about 50 of these pumps in use of various sizes, from 12 to 60 in. diameter, some of which have been over two years at work, and they are applied to various purposes, including the raising of water from 10 to 40 ft. height and the circulation of water in surface condensers and refrigerators.

Mr. IMRAY exhibited specimens of the castings forming the halves of the helical pump, and the internal paddlewheel; and also two working models, the one showing the pump in a vertical plane, revolving on a horizontal shaft, and the other in a horizontal plane, revolving on a vertical shaft. He mentioned that, though the helical pump seemed rather better than other rotary pumps for lifting water above itself, it did not seem so good for raising water up to itself by suction. The reason appeared to be that in other rotary pumps generally the water acquired its velocity in the pump itself, entering it at a low speed and leaving it at a high speed, and consequently the atmospheric pressure had only to support the suction column and impart the slow velocity of supply; whereas in the helical pump there was no acceleration in the pump, as the water left the blades at the same velocity as that at which it first met them, and it had therefore to acquire its full pace before entering the pump, and thus the atmospheric pressure had not only to support the suction column but also to impart the full speed to the water.

Mr. C. W. SIEMENS enquired whether in the model exhibited, in which the pump was placed a few inches above the surface of the water, there was a foot-valve at the bottom of the suction pipe, and whether the pump was charged with water previously; he did not see how the pump could otherwise raise the water to itself by suction.

Mr. IMRAY replied that there was a foot-valve, and the pump was charged beforehand. The deficiency in power of suction was shown by the circumstance that the helical pump would draw by suction from a depth of about 10 ft., but not well beyond; but other pumps would draw from a greater depth, up to 20 ft. or more.

Mr. E. A. COWPER asked whether any experiments had been made to ascertain the depth from which the helical pump would draw. His impression was that, when once charged and the water put in motion through the pump, it would be able to draw as much as 20 ft. or more.

Mr. IMRAY replied that there had not been any careful experiments made yet upon that point. The difficulty of raising the water by suction was experienced more particularly when the pump was placed vertically, because there was then a lodgment of air in the upper part of the pump casing, which interfered with the suction; but when the pump was placed horizontally this difficulty was overcome, and the suction was much more effective.

Mr. C. W. SIEMENS said he was much struck with the novel mechanical idea involved in the helical pump, of propelling the water by putting it as it were into a sling, and slinging it forwards. That this pump would compare favourably with the ordinary centrifugal pump he had no doubt, because, as pointed out in the paper, the water was not diverted from its course by abrupt changes of direction, and therefore very little power could be lost by eddies. The height of lift, as shown in the paper, was readily determined; for if the velocity of the pump were given, the height was known to which the column of water would rise to be in equilibrium, and half that height would in all probability produce the greatest amount of useful effect. It occurred to him that this pump would be extremely useful for lower lifts than other rotary pumps were generally employed for. As a turbine also he thought it would have certain advantages, inasmuch as the water in passing through a large wheel of that kind would be very little mutilated, and there would be very little loss in the way of eddies, provision being made for the water to expand into a larger channel before its final discharge; and it appeared to him that the construction admitted of almost unlimited extension in dimensions or number of turns of the helix, so as to utilise large amounts of water power. He should be glad to know whether it had been so applied and with what results. It appeared to him also that if ever the idea of ship propulsion on Ruthven's plan of a water jet should be taken up, this pump would particularly recommend itself as a propeller for such a purpose, because the water would not be taken into the ship in one direction and discharged in another after having its motion changed or even reversed; but it

might be taken in at the front and expelled toward the stern in the same line, passing in a continuous course through the helical channel of the propeller. These were applications that occurred to him on now first becoming acquainted with the helical pump; and he hoped to see many applications made of the principle, which appeared to him to be very novel and ingenious. With regard to the blades of the paddlewheel, it had naturally occurred to him at first that it would be better to place these at an inclination across the face of the wheel, so as to be exactly at right angles to the curve of the helix, and this he thought would be the proper position theoretically; but as that inclination would introduce an end pressure on the axis of the rotating wheel, which would probably do as much harm as would counterbalance the increased efficiency obtained, it was no doubt preferable to set the blades parallel to the axis of the wheel, as shown in the drawing.

Mr. IMRAY said that Mr. Boulton had been much engaged in endeavouring to apply the helical pump for the propulsion of vessels and as a turbine; but these applications had not yet been worked out practically. A curious fact to be mentioned in connection with the working of the pump was that, on putting two of these pumps upon the same shaft, both being of exactly the same size and driven at the same velocity, so that each should raise a column of water say 12 in. high, then if the discharge from the first pump were made to serve as the supply to the second, the column would be raised 24 in. high, or double the height given by either pump separately, though the velocity of the pumps was not increased. It was on this principle that the use of the pump as a turbine was being sought to be carried out. If only a single pump like that described in the paper, having two complete turns, were used as a turbine, it was evident that in order to develop any considerable amount of power the speed would have to be very high, and there would consequently be a great loss of power in the water going away at the high speed of the wheel; but if the water were made to enter at a slow velocity, and were taken up by wheel after wheel in a succession of helical pumps, and were finally discharged at

the same slow velocity, a large amount of power would be obtained from it, and the loss would be much smaller than in the other case. This seemed therefore the preferable course to take in applying the pump in place of a turbine; otherwise he thought it would not be so good as a turbine.

Mr. E. Reynolds remarked that when used as a propeller for ships the helical pump would have the advantage that it would reverse like an ordinary paddlewheel, thereby getting over one of the difficulties in hydraulic propulsion. With reference to the necessity for employing a foot-valve in the suction pipe of the pump, he had made some experiments which had satisfied him that the difficulty from the absence of a foot-valve was imaginary. During several years he had made experiments upon water ejectors or jet pumps, in which a jet of water was used, varying, according to the height to be lifted, from $\frac{3}{16}$ to $\frac{1}{4}$ in. diameter, and delivering itself into a cylindrical barrel $\frac{3}{4}$ in. diameter and about 3 in. long, the head of water for the jet being 240 ft.; but owing to the reduction caused by friction, the actual pressure at the jet was only 105 lb. per sq. in. The water was raised to various heights, the greatest in actual use being 25 ft., of which about 10 ft. was by suction; the extreme height to which it could be lifted had not been tried. When these jet pumps were first used, they were naturally placed below the level of the water to be lifted, as had been suggested to be necessary with the helical pump; but in a particular instance, in excavating the foundations for an engine, where the jet pump became frequently choked by cotton waste and other obstructions and it was very inconvenient to lift all the pipes and clear it, the experiment had been made of raising the pump above the water to a total height of about 14 ft. without applying any foot-valve in the suction pipe, to try whether the pump would charge itself by turning on the water jet gently at first so as merely to fill the barrel and suction pipe, and whether the air would by this means be expelled. To his great surprise this answered perfectly, the pump becoming fully charged in $\frac{1}{4}$ min.; and all the numerous pumps of that description which

were now at work were so arranged, being placed at heights varying from 10 ft. to 14 ft. above the water. Many of these jet pumps had not been seen since they were fixed seven years ago; but as the foundry pits and other places where they were fixed continued dry, it was assumed that the pumps continued working, the water jet being kept on constantly in those cases. He had also tried charging an Appold centrifugal pump in a similar way; it was used to pump out the water in excavating a large foundation, and the foot-valve was constantly choked by gravel so as to be inoperative. He tried the experiment of merely starting the pump at full speed, and priming it with buckets of water poured in at the open trough into which the pump delivered, a temporary dam being placed across the trough near the delivery orifice of the pump, thus letting the revolving arms strike the water so as to expel the air mixed with the water. This answered the purpose perfectly, and thus removed one of the difficulties in the use of that class of pumps.

Mr. C. E. Amos observed that the principle of the helical pump appeared to involve the same necessity as other rotary pumps, namely that it must be driven at a speed corresponding with the height of the column of water to be lifted. The reason for the helical pump not drawing the water from a lower level by suction he considered to be that the air could enter at the centre, at the joint of the rotating paddlewheel, and so prevent the pump from drawing water; but the Appold centrifugal pump was entirely closed at the centre, and was consequently enabled to draw by suction. Moreover to raise any large quantity of water, the helical pump would have to be made of large dimensions, probably three or four times as large he thought as the Appold pump for delivering the same quantity of water. If a careful comparison were made, he thought it would be found that the Appold pump or others of the same class were the best for raising large quantities of water, as in the case of heavy drainage operations and other works of that kind.

Mr. E. A. Cowper said that having seen the helical pump at work he considered when once full of water it would draw by suction as well as any centrifugal pump, if it was provided that water should pass through it; and water could if necessary be supplied through a by-pass from the delivery pipe into the suction pipe, so as to allow the water to pass through, and then when the pump was started at full speed the by-pass could be closed. In putting in a foundation with the aid of an Appold centrifugal pump, he had used a foot-valve and had charged the pump with water before starting, and had found it successful in drawing the water by suction from a depth of 26 ft. That was accomplished simply by driving the pump fast enough to throw water out; and of course if the pump were made to throw water out, it must be drawing an equal quantity in through the suction pipe. The helical pump might have to be made a little larger than a centrifugal pump to do the same work, but it was a very convenient form, and not at all likely to get choked up,—not so likely as where there were smaller passages. The application of the helical pump for circulating the condensing water through surface condensers would seem to be a very suitable one; and another excellent application he thought would be to sewage, where the height of lift was moderate. From 10 ft. to 40 ft. height of lift had been mentioned in the paper as having been attained with the pump, and he supposed the latter was the greatest height that had been tried; he should be glad to know what duty had been obtained at that height; it would perhaps not be the highest duty of which the pump was capable, but it might be expected to be a fair duty. It was an advantage in the helical pump that it did not require to be driven so fast as an Appold pump, which had a smaller disc and had accordingly to be driven at a higher speed for the same height of lift. The helical pump that he had seen at work was driven by one of Brotherhood's three-cylinder engines, which ran at a high speed and was consequently attached direct to the shaft of the pump without the intervention of gearing.

Mr. P. Brotherhood mentioned, in reference to the suggested use of the helical pump for hydraulic propulsion, that he had tried

some experiments two or three years ago with that object, and thought there were the germs of success in them; but the trial boat, instead of being made to draw only 4 in. as had been intended, had drawn 18 in., and consequently a speed of only about 4 miles per hour had been obtained. If the principle of hydraulic propulsion was a sound one, he thought the helical pump was the machine to apply for carrying it out.

Mr. IMRAY said that, with regard to the size of the helical pump for performing a given amount of work, he did not see that it must necessarily be larger than an ordinary centrifugal pump. To get a certain velocity of water current at a certain radius from the centre, it was necessary either to have a pump of large diameter driven at a moderate speed, or a small one at a high speed; at the same speed the diameter would have to be the same in the two cases for producing the same result. The area of channel round the helical pump was not made in practice more than about one quarter of the area of the suction or discharge pipe; the water consequently acquired an increased velocity on entering the pump, and lost it again on leaving the pump. The power expended on the pump with high lifts had not been measured; all that had been tried was whether the pump would lift high, and he had satisfied himself that it would, having attained a height of 40 ft. in the trials already made. In measuring the power expended with lifts of from 3 in. up to 12 ft., he had found so remarkable a uniformity in the percentage of useful effect obtained, that he thought it would continue for still higher lifts also.

The PRESIDENT observed that the helical pump appeared extremely ingenious and very simple, and from its very simplicity there seemed to be some difficulty in at once understanding the principle upon which it acted; the subject was one which would usefully exercise the attention of engineers. He proposed a vote of thanks to Mr. Imray for his paper, which was passed.

The Meeting then terminated.

The Helical Pump was shown at work to the Members on the same day at Messrs. Brotherhood and Hardingham's Works.

On the following morning an interesting specimen of Perkins' Steam Boiler and Engine for very high pressure and great expansion, having recently been opened for inspection by the Admiralty Boiler Committee after thirteen years' work, was shown to the Members at Messrs. Perkins' Factory.

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